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SUPPLEMENT TO SPONS'

DICTIONARY OF ENGINEERING,

Civil, Mechanical, Military, and Naval.

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DIVISION II.

LONDON:

E. & F. N. SPON, 46, CHARING CROSS.

NEW YORK: 446, BROOME STREET.

1880.

diameter in a depth of x ft. will be $\frac{1 \cdot 5\, x}{12}$ ft. Thus if the thickness of the overlying water-bearing cover be 100 ft., the reduction at that depth will be $\frac{1 \cdot 5 \times 100}{12} = 12 \cdot 6$ ft.; if the diameter of the shaft outside the brickwork is to be 15 ft. 2 in., the excavation must be begun with a diameter of 15 ft. 2 in. + 12 ft. 6. in. = 27 ft. 8 in.

When the sinking has been laid out to the requisite diameter, and the surface soil removed to as at a depth as the ordinary method of curbing will safely sustain, a strong wooden curb, about 6 in. by 6 in. in section, and of a diameter 6 in. less than that of the excavation, is placed in position at the bottom, and perfectly concentric with it. The piles to be used should be about 6 in. by 3 in. in section, and from 10 ft. to 15 ft. in length; their lower ends should be pointed and shod with iron, to enable them to penetrate the rock, and their edges should be planed true and bevelled, so as to form a close joint, when placed in contact around the circular curb. These piles are then driven down side by side against the outer face of the curb, care being taken to keep them vertical, that their edges may remain in contact throughout the length. A wooden maul is the most suitable instrument for driving the piles, and where the ground is strong, the piles should be hooped at the head, to prevent them from being crushed and split by the maul. It will not often be possible to drive the piles down to their full length at once; usually about 5 ft. will be practically the limit. Supposing the piles to have been driven down to this depth, the earth will be taken out from the inside to a depth of 3 or 4 ft. or less, according to its strength, and another curb of the same diameter laid to support the piles. When the support of the curbs has been substituted for that of the earth, the piles are again driven down as far as they will readily go, and the excavated from the inside, other curbs being placed to support the piles. These operations are repeated until the piles have been driven down to their full length.

When the earth has been excavated to within, say, 3 ft. of the lower ends of the piles, and a curb laid at that depth to support the latter, another curb, 18 in. smaller in diameter than those previously laid, is placed inside the bottom one, and 3 in. distant from it all round. Into the annular space between these curbs, a fresh course of piles is set, and driven down as far as they will go, and the operations of excavating, curbing, and driving are gone through as before. On approaching the foot of this second course of piling, another curb, 18 in. less in diameter than those just put in, is laid within the bottom one, and a third course of piling is set in the annular space between them, and driven down. These operations are repeated until the stone head is reached. When the stone head is reached, the wedging curb is laid, and the walling or tubbing erected as quickly as possible. The space between the shaft lining and the piling is filled up, as the walling or the tubbing proceeds, with clay.

The method of piling followed on the Continent differs somewhat in detail. The piles used are about 3 ft. long, from 4 in. to 5 in broad, and 1 in. thick. Instead of being driven into the ground vertically, they are given an outward inclination of 10° or 15°. When these piles have been driven in to their full length, the earth on the inside is excavated to a depth of about 2 ft. 6 in., or 2 ft. 9 in.; and before the thrust of the earth has brought the piles into the vertical position, a second curb is placed to support them. Around this curb, a second course of piling is driven as before, in diverging directions, and the earth again excavated. If the piles preserve their inclined direction, another set is driven vertically behind the curbs, and the space between the two sets is filled in with bits of wood. All systems of piling for passing through water-bearing beds are merely modifications of the two foregoing.

Water-bearing drift deposits may frequently be passed through by the method of backcasing. As the sides of the excavation will not stand alone if the height exceed a few inches, curbs will have to be put in very frequently, at intervals of three or four courses of bricks. Also the length of the segment to be bricked at one time must be reduced in a proportionate degree; one-tenth of the circumference being as much as may be removed with safety. It will be necessary to support the curbs from above, in ground of unstable character; and may be effected by means of stringing deals spiked to the curbs and to balks of timber at surface, in the manner adopted for wooden curbing. Iron rods constitute a better means of suspension than the deals, and should be 1½ in. in diameter, one to each segment. The usual mode of fixing the rods is to pass them through the bottom curb and through the balk of timber at surface, and to secure them to those pieces by nuts. This mode of suspension will be adopted when the bottom of the course of walling has been reached, and the sinking is to be continued in some other manner; as, for example, by means of a drum, when a bed of quicksand is met with. When the quicksand is encountered at a considerable depth, the lower course of walling may be suspended, by means of iron rods, from an upper course, instead of carrying the rods to surface.

The method of backcasing, though generally successful in even very wet marl, is inapplicable to quicksands, by reason of the tendency of the sand to flow with the water into the excavation. When such beds are met with, it becomes necessary to have recourse to piling, or to the brick drum. In the method of sinking with the drum, generally followed in the Lancashire district, when a bed of quicksand is encountered beneath some fathoms of cover, the backcasing, which has been put in down to this point, is suspended by means of iron rods from balks of timber at surface. The first operation is then to construct the drum to support the sides of the excavation, and it may be of wood or cast iron. If it is to be of wood, a sufficient number of oak curbs, usually 6 in. in breadth by 4 in. in depth, are placed at intervals of 2 ft. or 2 ft. 6 in. apart, until a length is made up greater by a few feet than the thickness of the bed to be passed through. Upon the outside of these curbs are firmly bolted, with their edges in contact, pieces of planking, called lags. This lagging is to take the place of the back sheathing, in the method of wooden curbing, and as the pressure against it will be great, it should have a thickness of 3 in. The edges of these pieces should be truly planed to the circle of the excavation, so that when placed in contact they may bear evenly and fully upon each other; this equal distribution of pressure may

be best attained by limiting the breadth of the lags to 4 or, at most, 5 in. Constructed in this way the drum resists like an arch, and it can yield only by the destruction of the material by compression. The arch is composed of the lagging alone, the curbs merely serving as supports to keep the elements of the arch in their places. The true fitting of the joints is also necessary to keep out the water, for the drum is to serve as a short length of tubbing at that portion of the shaft where the quicksand occurs. Around the bottom of the drum, and on the outside, a plate of iron, about 2 ft. broad, is bolted so as to project half its breadth beyond the lower end of the drum. This plate is called the leader, and its use is to enable the drum to cut its way into the sand or soft clay.

The drum is lowered into the shaft and brought to rest with its cutting edge upon the bottom of the excavation; to give the drum weight, the spaces between the curbs are filled up with brickwork. The sand is then carefully excavated from the inside of the drum, which sinks through the bed, the leader cutting its way down as the resistance is diminished by the removal of the sand. Sometimes the friction against the sides of the drum will cause it to stick, notwithstanding the weight of the bricks inside; additional weight is applied in the following manner. Four pieces of timber, two bearers and two cross-pieces, are laid upon the bottom curb so as to leave a rectangular opening in the middle, and pieces of board are laid upon these timbers around the central opening. Upon this staging, bricks are built up to the top, or as far as may be needed to give the requisite weight. When the drum has sunk through the sand, and a few feet into the clay beneath to form a water-tight junction, the sinking may be resumed in the usual manner, by backcasing to the diameter of the curbs inside. When the permanent walling is put in, it will be built up inside the drum, which merely serves as a backcasing; but the curbs may sometimes be recovered.

Though a wooden drum may be run to a much greater depth than a course of piles can be driven, it is urged as an objection to this drum that it reduces the diameter of the excavation to the same extent as the piles. To remedy this, wrought iron, in ½-inch boiler plate, has been substituted for the wood. But, as G. G. André remarks, in his excellent work on 'Coal Mining,' to which we are largely indebted for this article, the liability of these drums to collapse renders them far more objectionable than wooden drums. Drums of cast iron are constructed in segments, in the same manner as ordinary tubbing, but with the flanges and strengthening ribs on the inside, so that the outside of the drum may be smooth to allow it to sink through the sand. Such a drum will seldom need to be weighted, and the reduction in the diameter of the excavation occasioned by it will not be more than half that due to the wooden drum. A well-constructed cast-iron drum may be run in so as to constitute a portion of the permanent lining of the shaft, and when this can be accomplished, the cast-iron drum will afford the most economical means of passing through a bed of quicksand.

In Germany and in Belgium, a method of sinking through quicksands is adopted very similar in character to that of the drum used in England. In this method, a cylinder of masonry is substituted for the wood or iron of the drum, and the masonry is made to rest upon wooden curbs, the bottom one of which is furnished with an iron leader, to enable it to cut its way through the sand. A similar method of sinking a shaft was adopted by Brunel in excavating the Thames Tunnel.

In the Anzin coal district of France, beds of quicksands, locally known as torrents, are met with below the chalk marl, 70 to 80 yds. from the surface. When the excavation has been walled down to near the quicksand bed, a wooden curb, of the same diameter as the shaft, is wedged against the rock beneath the walling. The use of this curb is to afford a point of support against which screws may be set during subsequent operations. Besides the wedging, two bearers are placed across the shaft above the curb, and firmly fixed into the rock, to prevent the curb from being forced up by the pressure to be brought against its lower side. An oak curb, of the dimensions of those used for tubbing, is then laid upon the sand, at the bottom of the excavation, and beneath the wedged curb. This oak curb is provided with a cutting edge, by bevelling the under side, that is, the outer face is made twice the depth of the inner face. Around the outside of the curb, an iron plate is screwed to form a leader, the heads of the screws being countersunk, to avoid projections on the outside, and the lower edge of the plate being allowed to extend an inch beyond the wood. The segments of the curb are joined by tenon and mortise, and the joints are strengthened by iron straps. Pressure screws, to be applied after the manner of a lifting jack, 4 in. in diameter, and from 8 ft. to 10 ft. in length, are then set upon the cutting curb, and made to abut against the wedged curb placed above for that purpose. When the cutting curb has been got perfectly level, and the screws have been tightened, the former is pressed down, by turning each of the latter about one-third of a revolution in succession. As soon as the sand appears behind the descending curb, and on a level with its upper side, means are taken to prevent it from flowing over into the excavation, by driving in pieces of fir sheathing, sometimes preceded by straw bands. The jack screws are then removed, and a second tubbing curb, of ordinary construction, is laid upon the first, and bound to it by means of vertical iron straps, nailed on simultaneously at several equidistant points. The screws are then replaced, and the tubbing is again forced down, until the second curb is on a level with the sand. A third curb is then placed upon the second, and strapped to it in the manner described; the sand displaced by the curb is removed, and the three are again forced down. These operations are repeated, until the lowest, or cutting curb, has entered the clay beneath, when the shaft, throughout the length occupied by the sand bed, will have been securely tubbed. Pebbles are picked out from beneath the cutting edge by means of tongs. When the clay has been reached, the sinking is carried on in the usual manner, until a foundation for a wedging curb is met with, upon which the wood tubbing is carried up to the cutting curb. The bevelled edge of the latter, with its iron leader, is then cut away in portions, leaving its under side level, and a curb of suitable thickness is inserted, to join and complete the tubbing.

Another method of sinking through the upper water beds of this district partakes of the character

of the preceding, and of that of piling. The excavation having been begun of a sufficient diameter to allow of the subsequent necessary reductions, is carried down till the water is met with, when the bottom is levelled, to receive a wooden curb. This curb, which is generally polygonal in form, is 4 in. in breadth, and 12 in. in depth, and it is strengthened at each of its angles with iron straps. Behind this curb, piles are set, and driven down vertically side by side, so as to form a close joint. These piles are 6 ft. to 7 ft. in length, 4 in. broad, and 1 in. thick, and they are first driven down about half their length. The sand or marl is then removed to a depth of 12 in., which is equal to the depth of the curb. A second and similar curb is laid upon the first, and the two are driven down, by mauls, to the bottom of the excavation. The earth is again removed to a depth of 12 in., a third curb is laid upon the second, and the whole are driven down with the maul, as before. During these operations, the piles are kept in advance of the bottom curve. If the curbs become fixed by the pressure against them before the foot of the piles is reached, the remainder are put in from below. When a tubbing of curbs has been put in, in this manner, to nearly the length of the piles, a curb of the same sectional dimensions, but of 10 in. less external diameter, is laid within those already fixed, and on a level with the lowest; and a second series of piles is driven in between the inner and outer curb. These piles are not driven in to their full length, but are left to stand out about 12 in., so that they may be nailed to the first series of curbs, should the forcing down of the second carry the piles with it. This second series of curbs is sunk in the same manner as the first, and the same operations are repeated for all the subsequent series needed. This method has been successfully adopted in numerous instances.

The Kind-Chaudron system, which consists in boring out the shaft from the surface by means of apparatus similar in character to that used for prospective borings, has been successfully applied on the Continent.

Opening out and the driving of narrow ways have been previously referred to in this article at p. 370.

The first operation in getting the coal is to remove the support from beneath it by undercutting. This consists in cutting a groove along the bottom of the seam to a depth of 2 ft. 6 in. or 3 ft. The object of good holing or undercutting is to remove the support of the superincumbent coal with the least possible waste or creation of slack, especially with thin seams, in which case it is preferable to hole in the under clay. Holing in the under clay is, however, not always feasible on account of the nature of the clay; the operation is frequently effected in the partings, or shaly deposits, beneath or separating two bands of coal. When the holing is made beneath or in the lower portion of the seam, the layer of shaly or pyritous matter constituting the parting falls with the coal and becomes mixed with it, depreciating the value of the produce. Coal so mixed with dirt is said to be fouled, and is described as dirty coal. Before hewing is commenced, the wall-face is divided into lengths or stints of about 2 yds., one length being allotted to a hewer. If the holing is to be at the bottom of the seam, the hewer lies upon his side, in order to cut the groove as narrow as possible. The best hands will hole to a depth of 3 ft. or 3 ft. 6 in. without exceeding a height of 12 in. on the face. In order to have sufficient room to swing the pick in, the height of the holing is kept at nearly 12 in. for some distance in, and then gradually reduced to nothing at the full depth. This gives an average height of about 9 in. for the whole holing. The hewer, having cut away the face to begin the holing, chips away the coal or the clay. He then clears out the débris which encumbers the groove, and repeats the blows, working forward in this manner from one end of his stint to the other. In holing to a depth of 3 ft. or 3 ft. 6 in. the hewer places himself almost beneath the coal, and as the latter is apt to fall when the support is removed from beneath it, the coal has to be propped or spragged at intervals. Generally the coal requires to be detached at the sides as well as at the bottom, to ensure its fall in a mass. In narrow workings, as in the driving of levels, this side cutting is indispensable. The operation known as shearing consists in cutting a vertical groove, similar to the holing at the bottom. In narrow places, one side is often sheared and the other broken down by blasting, and this expedient is resorted to in long-wall wide workings, to avoid the necessity of shearing. The latter operation will have to be adopted at intervals, the frequency of which will increase with the strength of the coal. The advantage of blasting is merely gain of time, because as much small coal is made by the blast as by cutting.

When the holing and shearing have been completed, the coal has to be removed from the seams, involving three operations—falling, breaking-up, and loading, usually performed by two different sets of men. To fall the coal, the spraggs are removed, and the coal sometimes falls by its own weight. But when the coal is resisting recourse is had either to wedges or explosives. When wedges are employed, they are driven in with sledges between the coal and the roof at intervals of a few feet apart; and to complete the falling of the mass, the iron bar is used. When the coal is very strong, and often when it is not strong, the falling is effected by gunpowder. A few shot-holes are rapidly drilled by hand in the upper part of the soft coal, and lightly charged. A light tamping of shale is forced in, and the blast is fired quickly. The coal is much more broken by this means than by the wedges, but the effectiveness of the operation, and the ease and rapidity with which it may be performed, are usually sufficient to induce the miner to adopt it in preference to that of wedging, notwithstanding the better condition in which the latter leaves the coal.

When the coal has been brought down, it is broken up into blocks as large as can be conveniently handled, and conveyed in tubs to the shaft to be raised to surface. Coal, like rock, increases largely in bulk when broken up, and this must be considered in an estimate of the cost of a driving and in making provision for the execution of the work. It is impossible to estimate what the exact increase of bulk will be in any given case, but a general average is to be attributed to the following proportions;—

The increase in the bulk of coal when broken up is in the proportion of 1 to 1·6; that is, a cubic yard of coal in the seam will occupy a space of 1·6 cub. yd. when removed and broken up. The value of 1·6 cub. yd. in feet is 43·2, and a tub having a capacity of 24 cub. ft. will contain

$\frac{24}{43 \cdot 2}$ of this quantity; there will be required $\frac{43 \cdot 2}{24} = 1 \cdot 8$ tub to convey away this quantity; in other words, one cub. yd. of solid coal will break up into 1·8 tub load. But the size of the tubs employed will materially influence the degree of increase in bulk, this increase being greater in tubs of small capacity than in those having larger dimensions. When small tubs are used, a relatively greater number of loads will be obtained from a cub. yd. of coal. Also the increase in bulk will be greater when the coal is strong, and, consequently, breaks up into large blocks. When the excavation is in rock, the distance of the shot-holes apart, and the strength of the explosive employed, will influence the increase in bulk. For when deep holes widely spaced are adopted, the rock is brought out in larger fragments than when the blasting is carried out in numerous shallow holes; and the stronger the explosive the more shattered is the rock. Generally the increase of bulk in the levels of a mine may be taken as 1 to 1·75 for coal, 1 to 1·70 for shale, and 1 to 1·80 for sandstone.

As there is an increase in bulk, so is there a decrease in weight. If the average weight of bituminous coal is 2133 lb. the cub. yd., its weight when broken up will be $\frac{2133}{1 \cdot 75} = 1219$ lb. the cub. yd. Hence, a tub having a capacity of 24 cub. ft. will contain 1080 lb. In like manner, the weight of shale being 153 lb. the cub. ft., that substance will weigh 90 lb. the cub. ft. when broken up; and the weight of sandstone being 158 lb. the cub. ft., this rock will weigh in a broken state 88 lb. the cub. ft. A tub of the same dimensions will, therefore, contain 2160 lb. of the former, and 2112 lb. of the latter.

To facilitate the removal of the coal and rock dislodged from the face of the heading, the floor should be laid with a double line of tram rails. These may be of light weight, and of any form that may be deemed suitable. When the driving is executed with the aid of machine drills, the floor is frequently laid with only one line, from which sidings are laid off as required. These tramways are only of temporary character, to be replaced by the permanent lines when the excavation is completed.

The danger and labour of undercutting by the pick is great and wasteful, even with a skilful hewer, in consequence of the large proportion of slack made, especially in thin seams. The difference in the amount of this slack which is made by manual and by machine holing is indicated by Figs. 853 and 854. In Fig. 853 the coal is undercut by the pick to a depth of 3 ft., the height of the cut ranging from about 16 to 18 in. at the face to about 2 in. at the back, or an average of 9 in. Fig. 854 shows the seam undercut to the same depth by machine, the cut having a uniform height of 3 in.;

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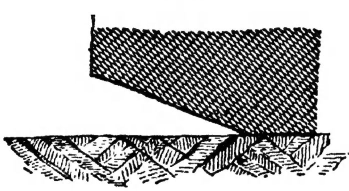

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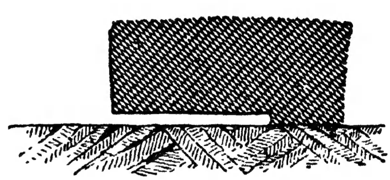
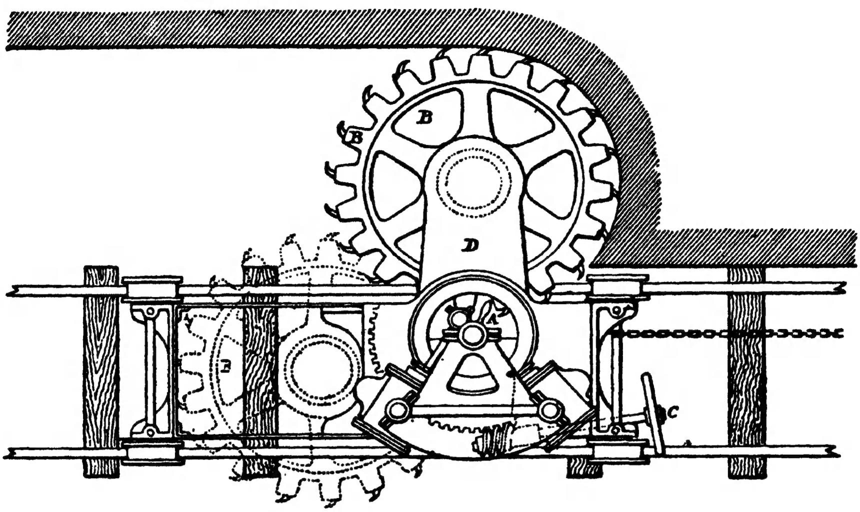


here but one-third of the quantity of slack is made, as compared with manual holing; and this represents a corresponding increase in the value of the coal got, the slack being comparatively worthless. Another advantage of machine holing is the increased rapidity with which the work can be carried on; a superior workman will undercut a face of about 5 yards of coal 3 ft. deep in a day of ten hours, in a coal of medium hardness, but this rate of progress is exceptional; while a machine in the same time would undercut as much as 150 yards, or even more, to a depth of 3 ft. In the pick action by hand labour most of the power is expended on the back stroke of the pick and in keeping it level. By turning a winch handle more than twice the power may be developed, and a wheel cutter actuated by this method by hand would be more effective than the pick action; and this arrangement has been successfully adopted in Lilienthal's manual-power coal cutting machine. One of the difficulties in coal cutting is the irregularity of the strata, especially in the roof; but as rapid working is always favourable to the maintenance of the roof, the use of the machine is of advantage, as by its use the undercut can be made and the coal taken away before the weight of the roof has time to come upon it; thus increasing the safety of the workings, and saving much of the expense which would otherwise be incurred for timbering.

Winstanley and Barker's coal-cutting machine, Figs. 855 and 856, consists of a small frame, running on four wheels, and carrying two oscillating cylinders, which may be driven either by compressed air or steam. On the crank shaft, and underneath the frame, is a pinion A, which gears into a coarse pitched toothed wheel B, the ends of the teeth of which are armed with cutters shaped as in Figs. 857 to 860, the manner of attaching them to the teeth of the cutting wheel being shown in Fig. 861; and these three forms of cutter are arranged in regular succession around the periphery of the cutting wheel B, which can be turned back under the carriage when not required, as shown by the dotted lines. When the machine has been placed in position, the cutting wheel is fed into the face of the coal by turning the handle C, until the arm D, carrying the cutting wheel, is at right angles to the carriage; the cut is then advanced by slowly dragging the machine forward, by means of a chain attached to a crab. As the machine advances, wooden wedges are driven into the cut to support the coal; when the machine has been moved out of the way these are withdrawn and the coal falls. This machine weighs 15 cwt., its height above the surface of rails being 22 in.; it will cut at the rate of 30 yards an hour with a pressure of 25 lb. a sq. in., making a holing in the coal 3 ft. deep and 2 to 3 in. in height.

The chief features in this machine are, that the swivelling movement of the arm carrying the cutting wheel enables it to cut or hole its own way into the coal, the depth of cut increasing from nothing to about 3 ft.; were it not for this arrangement, a portion of the coal would have to be cut out by hand labour, for the purpose of inserting the cutting wheel, unless the machine were started at the corner of a pillar, or a "loose end." It will also be seen that when the cutter wheel is drawn



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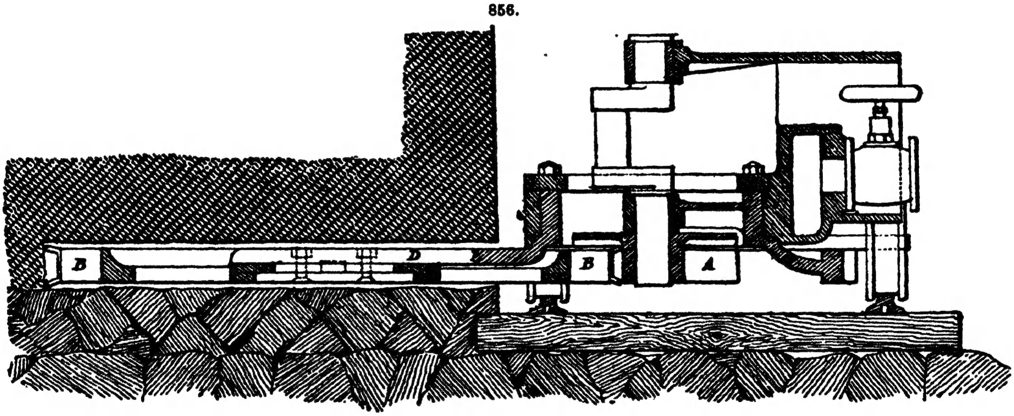

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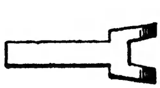

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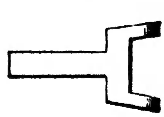

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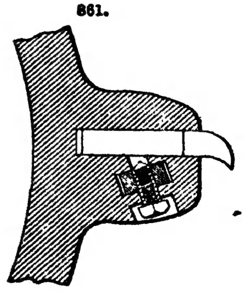
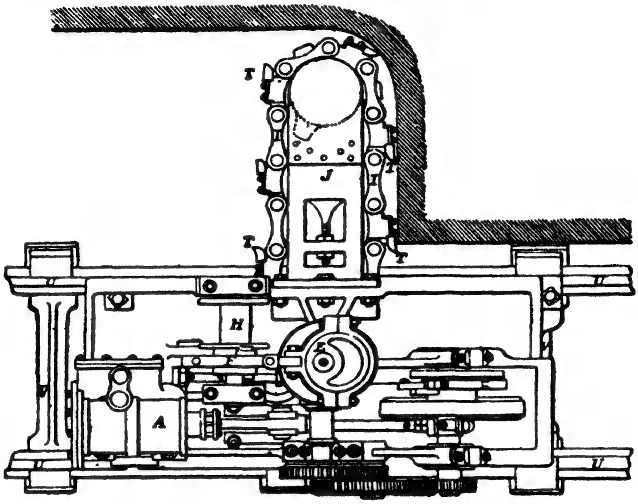


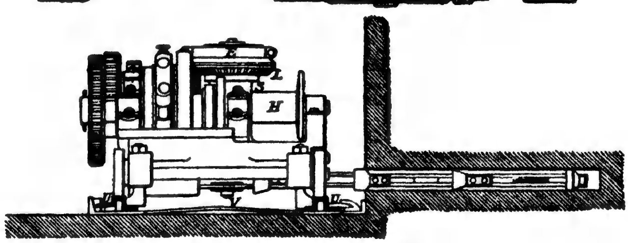
underneath the frame, the machine can be taken through narrow roads without the cutting wheel being removed; the space required for the machine to pass being not more than 4 ft., the diameter of the cutting wheel, with the cutters attached, being 3 ft. 8 in. Another important advantage in this machine is, that the power to drive the cutting wheel is applied direct on the circumference of the wheel; which mode of gearing also allows the small pieces of coal or slack to fall through to the bottom, so as not to block or clog up the teeth of the machine. A disadvantage possessed by this

machine, in common with many others, consists in its being able to cut on only one side of the carriage; so that when it is necessary to cut on both sides of a drift or heading, the machine requires to be turned round bodily, by means of a turntable or some similar contrivance.

In 1872 this machine had been employed for nearly two years at the Platt Lane Colliery, Wigan, in a seam of coal known as the "Pemberton Little Coal," which was about 2 ft. 4 in. in thickness, and so hard that it was worked with difficulty. The machine frequently cut the whole length of the face of 120 yards in nine hours, including all stoppages, the average work for one man with a pick being, in the same mine, less than 5 yards a day; a comparison of cost as against hand labour showed but a trifling advantage in favour of the machine.

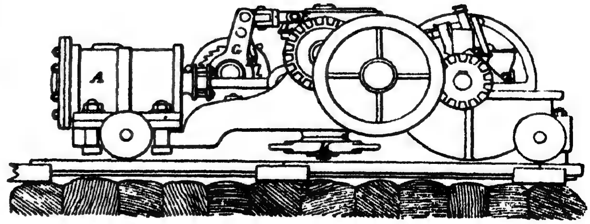
Baird's coal-cutting machine, also known as the Gartsherrie, is shown in Figs. 862 to 864. Fig. 862 is a plan, Fig. 863 an end elevation, and Fig. 864 a side elevation. It weighs 25 cwt., and the





frame on which it is supported measures 6 ft. by 2 ft. 6 in. A single air-cylinder A, 8½ in. in diameter and 12 in. stroke, propels the machine and also drives the cutters. This engine is driven at about 240 revolutions a minute; but the speed is considerably reduced by the gearing of the machine, and the cutters move slowly. From one of the sides of the frame a horizontal jib J is extended, round which passes an endless chain I, carrying the steel cutters T; there are altogether nine of these cutters, and when the cutting is commenced they are passed forward into the coal by the distended jib. The endless chain I is driven by a chain wheel K on the upright shaft S. This machine is self-propelling; its forward motion along the face is given by an eccentric E cast on the bevel wheel L, which is fixed on the upright shaft S, the straps of the eccentric E being connected with a lever G, driving the ratchet wheel R; and the chain which draws the machine forward is wound round the propelling drum H, on the shaft of this ratchet wheel, the other end of the chain being made fast in front of the machine.

864.

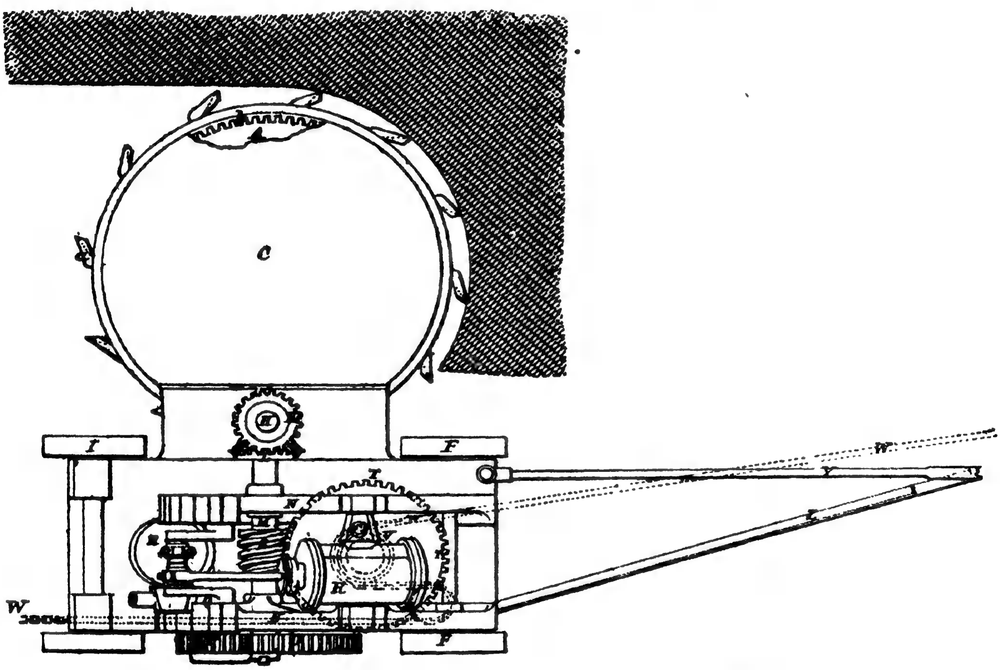


When cutting commences, the endless chain, with the distended jib, moves slowly under the coal, cutting at a rate varying from 9 in. to 15 in. a minute. Three men are required to attend this machine; another man is required to look after the chain, which is liable to get out of truth; and a man to sharpen the cutters, which are brought to bank for this purpose after every shift. The breadth of the cutters is 2⅝ in., and this represents the width of the groove made by the machine.

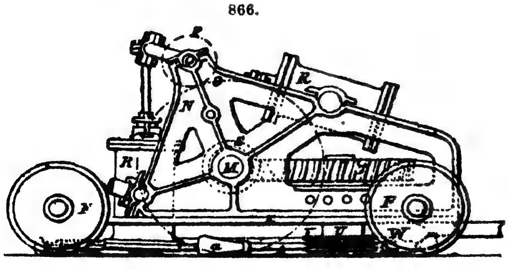
The machine is strong and solid; it is exceedingly compact; and the working parts are easy of access. When at work it is covered by a sheet-iron case, not shown in the drawings, to shield the gear from injury, and also to facilitate the moving forward of the rails and sleepers on which the machine runs. This road is formed of short pit-rails U, in 4-ft. lengths, fitting into cast-iron joint sleepers V. The rails and sleepers are regularly taken up behind the machine and passed forward, along the sheet-iron cover, to the man in front, who lays them down in readiness. The pressure upon these rails, due to the direction of the cut of the chisels, tends to draw them towards the coal face. The feed is self-acting, but the rate requires to be made variable, and this could easily be done by altering the arm G, which is worked by the eccentric E; the hauling barrel H should also be worked by a friction clutch, so as to allow it to slip when the cutters come across anything unusually hard, or from any other cause become jammed. The endless-chain form of cutter, adopted in this machine, is advantageous in working over an uneven floor; but the method of attaching the cutter to the chain, by means of bolts, is cumbrous and capable of much improvement, while the form adopted for the cutting teeth would not appear to be the best that could be devised for cutting, not scraping, the coal. This machine must be started from a loose end, and cannot be entered anywhere, as the Winstanley cutter can.

Gillott and Copley's coal cutter, Figs. 865 to 867. The machinery is mounted on a strong carriage, made sufficiently low to admit of the cutters getting well down to the bottom of the face.

865.



866.



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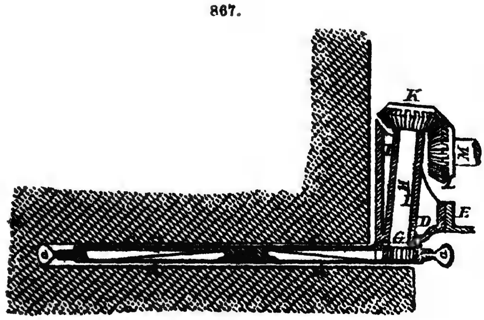

A is the horizontal cutting wheel, carrying in sockets a number of cutters *a*. The wheel revolves round the stationary centre B, fitted to the under side of the covering plate C, which is bolted to the under side of the fence bracket D, the bracket D is bolted to the bed plate E of the engine, the whole being mounted on travelling wheels F. The cutter wheel A has internal cog teeth, as at *b*, Fig. 865. In these a spur pinion G gears, the pinion is fixed on the lower end of the spindle H,

working in a long bearing I cast in the fence bracket. On the upper end of H there is a bevel wheel K, into which gears a corresponding wheel L on the driving shaft M. The shaft M works in bearings in N, and has keyed upon it the spur wheel O, deriving motion from the pinion P on the crank shaft Q of the engine. The crank shaft is driven by the two oscillating cylinders R, worked either by steam or compressed air. The action of this machine is as follows;—On starting the engine a slow but powerful rotary motion is imparted to the cutter wheel or disc A, the cutters a cutting out the coal from the bottom of the groove towards the face of the working. During this action the entire machine travels slowly along in order to keep the cutters well up to their work. This feed motion is derived from the endless screw S, on the shaft M, gearing into the horizontal worm wheel T, which is fixed on a short vertical shaft working in a collar-bearing U in the bed plate, and this shaft carries at its lower end a horizontal chain pulley V gearing into the chain W. The rear end of this chain is left free after first passing round or being returned over the guide pulley V′, as shown in dotted lines in Fig. 865; but its forward end is anchored some distance ahead of the machine, being first guided over a guide roller X, which is mounted on the ends of a pair of tension rods Y and a rigid T-iron bar Z, which project from the front end of the machine. The object of thus guiding the chain, along which the machine hauls itself forward, is to keep the machine well up to its work by resisting the tendency which it has to revolve round the centre of the cutting wheel.

Figs. 868 to 870 are an improved method of mounting the cutting wheel in this machine. A bevelled flange A, Fig. 869, is formed so as to project inwards from the upper surface of the

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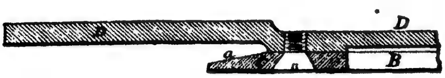
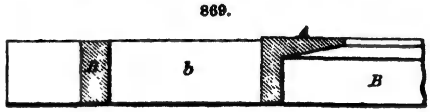


869.



cutter wheel, and a corresponding retaining strip B C, Fig. 868, is made concentric with this wheel, and is secured by screws on to the under side of the bracket D. The bevelled flange on the cutter wheel revolves in the space *a* between the retaining strip C and the bracket D, the wheel working freely on its centre E. The wheel is thus kept up to its cut by the combined action of the flange and strip, whilst at the same time the driving pinion which gears into the teeth *b* of the cutter wheel cannot get out of gear, since the wheel is prevented from springing by the pressure of the strip and flange.

870.

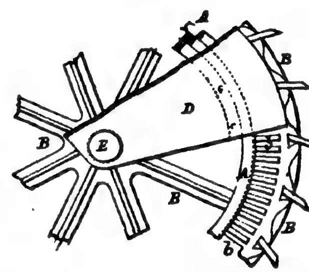
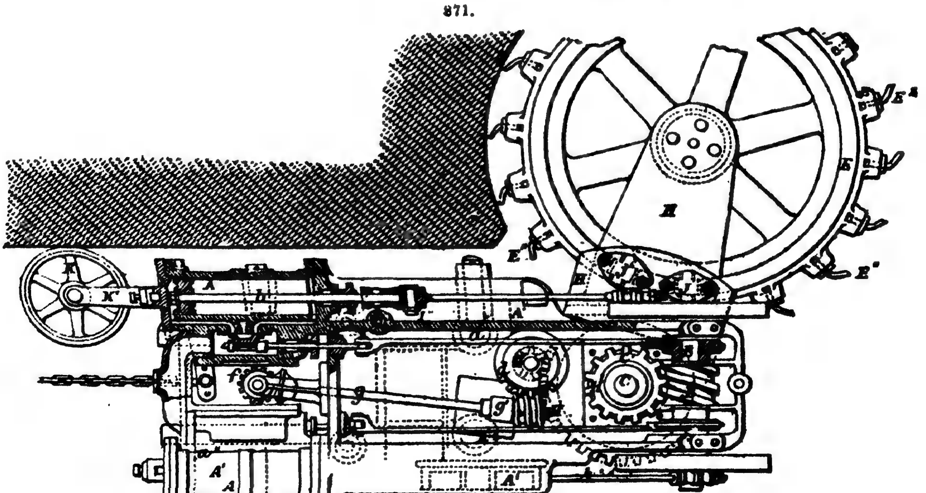


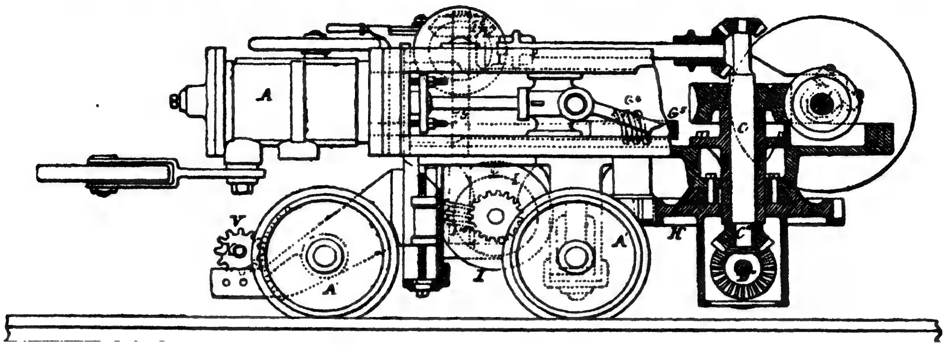
Fig. 871 is a plan partly in section, Fig. 872 side elevation, partly in section, Fig. 873 a cross section, and Fig. 874 a side elevation of Hurd and Simpson's coal cutter. The cylinders A are fixed to a framing supported on wheels, and the level of this framing and its angle can be adjusted by means of regulating screws. The piston rods of the cylinders A are connected to cranks on the crank shaft B¹; upon this is a worm gearing into C′ on the upright shaft C, at the lower end of which is a mitre pinion C², gearing into the pinion D², on the horizontal shaft D, on which is also fixed the bevel pinion D¹, gearing into the large bevel

871.



wheel E, supported on a bevel centre piece screwed to the radial arm H. This fits into the socket H, which has a toothed segment on part of its circumference; the pinion G is driven by a hand wheel, mitre *f*, horizontal shaft *q*, worm *g′*, and wheel *d*, and gears into the segment and

moves the cutter wheel E either to the right or left of the framing, as may be required. The large bevel wheel E is cast to E¹, in which the cutters E² are fixed. These are made of plain square steel, set sideways above and below, and central to allow for clearance of the disc, and are held in the stocks by set screws. The cutter stocks E¹ are eccentric to the fulcrum on which the large bevel wheel E revolves. When the wheel E revolves, the cutters act on the coal with greater



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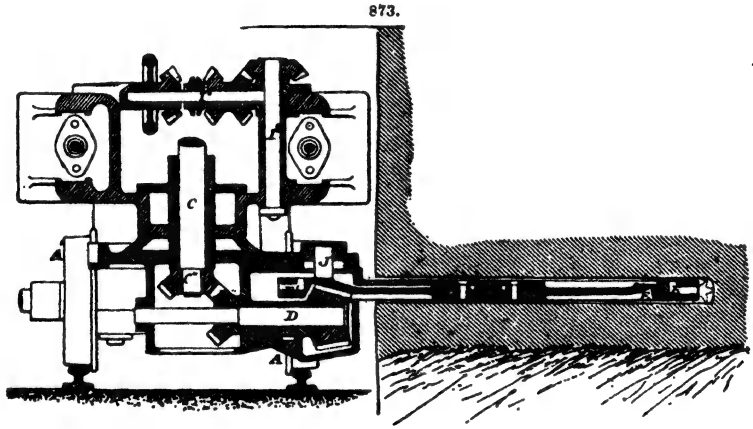

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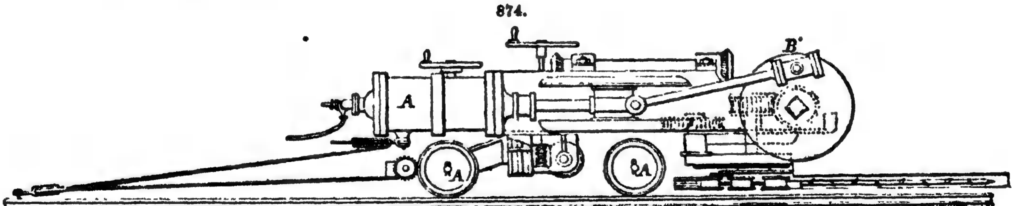

effect during one half of the revolution than they do at the other half, and while the smaller radius of the eccentric is towards the coal the whole machine is drawn forward in the direction of the arrow by the self-acting hauling rope, which is wound on the drum I by the bevel pinions I¹. To the shaft I² is fixed a bevel pinion, gearing into two wheels, which are loose on the cross shaft I'', but connected to it when required by a sliding clutch-box; to the cross shaft is fixed the bevel pinion, gearing into the wheel, on the upright shaft, to which is also fixed the worm, gearing into the wheel fixed to the axle of the drum I. The direction in which the machine is traversed can be reversed by moving the sliding clutch-box into gear with either of the clutches. As the larger radius of the eccentric wheel E comes into action the cutters take fresh hold of the coal, and these alternate actions are repeated until the whole seam is undercut. The pressure on the eccentric wheel E is resisted by the conical antifriction bowls J, which revolve in bearings fixed to the radial arm H and its socket, dispensing with guides and slides. The leading end of the machine is kept in position, so that the carrier wheels may keep on the rails when at work by means of the wheel K mounted on a differential elbow lever K¹, to which is connected one end of the hauling rope; this passes round a snatch-box, anchored at the end of the bank to be undercut, and is then taken back to the drum I on which it is wound, as shown in the side elevation, Fig. 874. The shaft X with the pinions V which gear into toothed wheels cast on the carrying

wheels, are for reversing the machine along the rails at inclines, or when it cannot be easily pushed along by hand.

In Figs. 875 and 876 this machine is arranged for driving levels or narrow work. It cuts to a depth of 2 ft. 6 in., the cutting wheel being of the same description as the cutters in the under-

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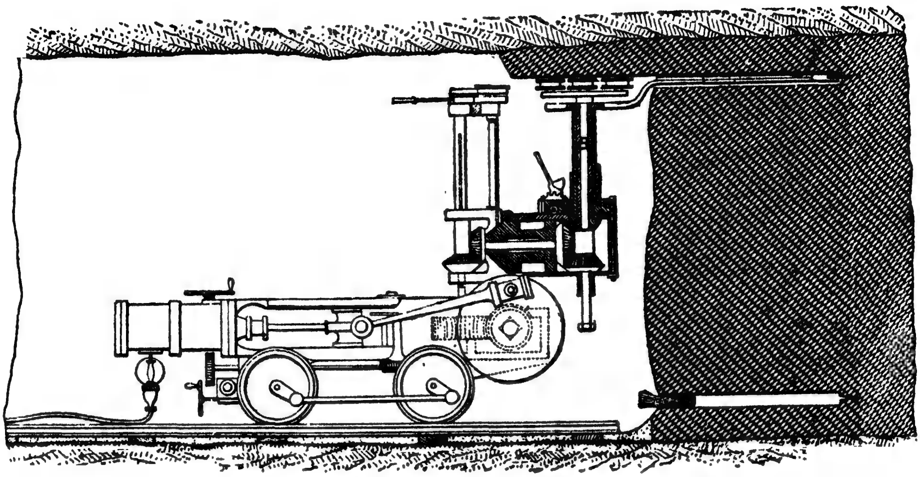

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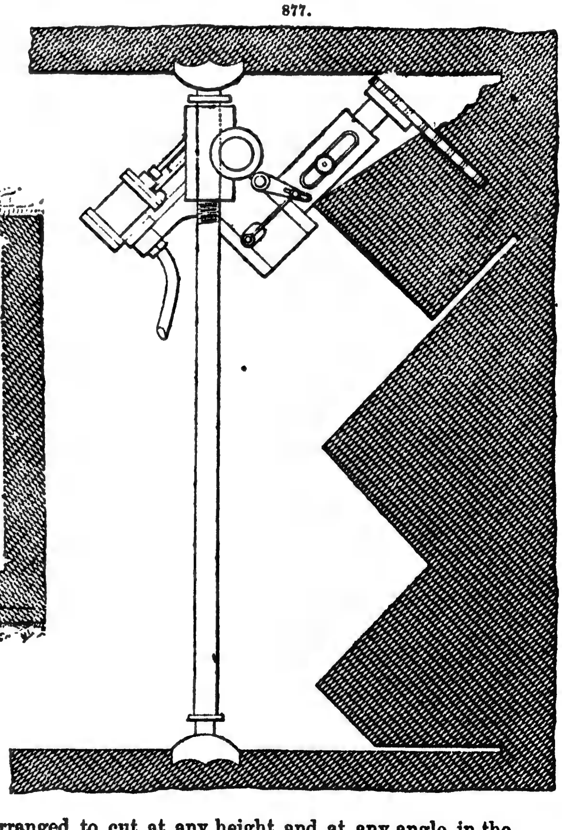
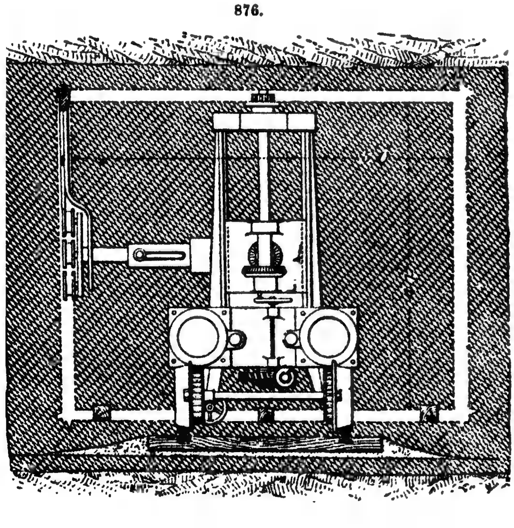


876.

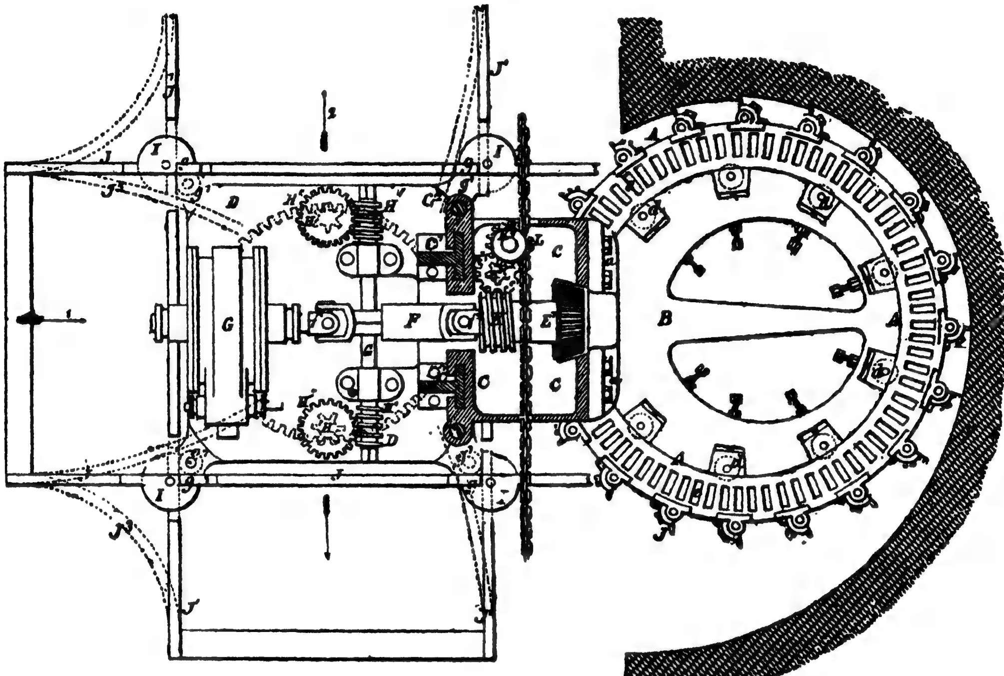


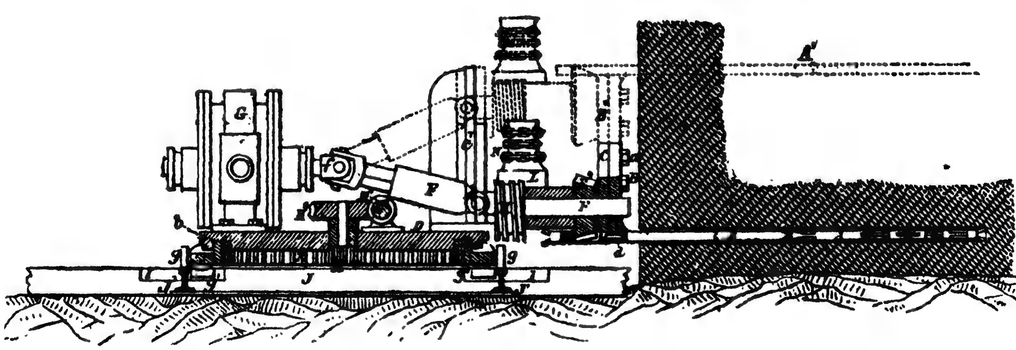
cutting machine. This cutting wheel is arranged to cut at any height and at any angle in the seam, and is supported on a telescopic shaft B, which, with the parts acting with it, are supported in slides, and can be swivelled round. The bottom groove is cut first, and the coal supported by wooden wedges; the side grooves are then cut, and sometimes, but not always, it is found necessary to make the top groove. The machine is then run back, the wedges removed, and the block of coal falls by its own weight or is brought down by wedges. Fig. 877 is a very small

machine constructed upon this principle, and mounted upon a stretcher bar in a manner similar to a rock drill. Its construction and mode of action will be understood from the foregoing description.

Fig. 878 is a sectional plan, and Fig. 879 a longitudinal section of Johnson's coal-cutter. A is the revolving cutter ring, to the periphery of which are secured the reversible cutters *j*. The ring is carried by the arm B, which projects from and is bolted at *a* to the adjustable

878.



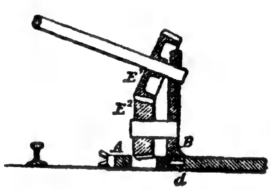


879.

bracket C on the frame D, which is fitted at *b* to the bed plate E, so as to admit of its turning freely without other independent movement. The cutting ring A is supported by small antifriction rollers *d*, carried by B contained within the cutter ring, except at the part connected with the frame. On the cutter ring A there is an annular rack *e*, gearing into a bevel pinion E′ mounted on the shaft F of the engine G, which is carried by the frame D. The bracket C is fitted to guides C′ on the frame, and can be adjusted vertically by means of screws C″, Fig. 878. This admits of the cutter ring A being raised and lowered, in order to cut at any suitable height, as A′, Fig. 879. To enable this vertical adjustment to be effected without throwing the cutter ring out of gear with the driving mechanism, the engine shaft F is made in sections connected by universal joints *f f*′, one section of the shaft being fitted to a socket in the adjoining section, which admits of the longitudinal extension or contraction of the shaft. By turning the frame D upon the bed plate E the cutter ring may be adjusted laterally to any angle without throwing it out of gear. This adjustment of the frame D is effected by rotating the shaft G′ provided with worms H′, which gear

into worm wheels H″ mounted on short vertical spindles carrying at their lower extremities toothed pinions H, these engage with segmental racks on the inner edge of the open bed plate E. The bed plate E is supported at each of its four corners by wheels *g*, the bearings of which are so pivoted that the wheels are capable of being turned upon the bed plate to either of two positions at right angles to each other, according as they are to run upon one or other of two railway tracks J or J′, which cross at right angles. The wheels *g* are unprovided with flanges, and are maintained upon the rails of the track by horizontal rollers *g′* suspended beneath the bed plate, and arranged to bear against the inner sides of the rails. At the intersections of the rails J and J′ there are segmental plates I, adjusted upon vertical pivots, so as to form continuations of either of the rails. When the machine is to be moved in the direction of the arrow 1, in order to cut the coal *y*, the wheels *g* of the bed plate are adjusted to the rails J, and the segmental plates I are turned into such a position as to form continuations of the latter, as shown by full lines in Fig. 878, and after the wheels *g* have crossed the segmental plates, and the rotary cutter has penetrated to the required depth, the wheels and segmental plates are adjusted to the positions indicated by dotted lines, and the machine is then traversed over the track J′ in the direction of the arrow 2, or in the reverse direction, as the case may be, the result of which is the cutting of a deep channel in the coal. As J and J′ are of the same gauge as usually laid for mine trucks, the latter may follow the machine to receive their loads; all that is necessary in order to transfer the trucks from one track to the other being to lay curved rails J^3 at the points of intersection, as indicated by the dotted lines. Cutters of various descriptions may be secured to the cutting ring, but they should in all cases be reversible. The cutter, Figs. 881 to 883, consists of a block V pivoted to ears *i*, and carrying two sets of cutting points *j* and *j′* facing in opposite directions. The cutting points have spaces between them, and are so arranged in respect to each other in the several cutters that the points of one cutter will remove the coal passed by the points of the preceding cutter, Figs. 882 and 883. When the movement of the cutting ring is to be reversed, the blocks V are turned upon their pivots *a*, Fig. 881.

880.



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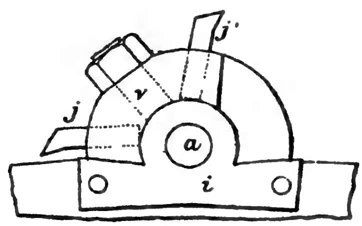

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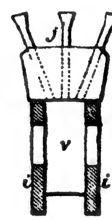

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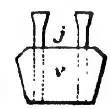
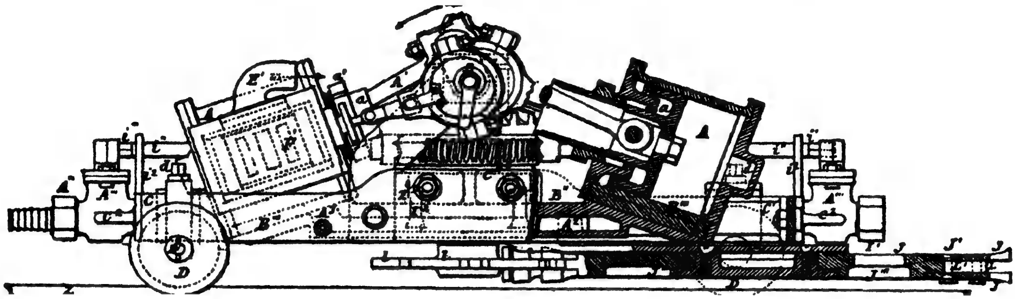


The machine is moved automatically upon both of the tracks. This is effected by arranging upon the driving shaft F, a worm K, to which are adapted the teeth of a worm wheel K^1, transmitting motion to a pinion K^2, which in turn operates a pinion K^3 on the spindle of the vertical capstan L, around which is passed, one or more times, a chain N made fast at its ends. When the capstan L is turned through the medium of the gearing above described, the chain is necessarily traversed, and the machine is thus moved along the track J or J^1, according as the chain is extended along one or the other. The capstan and its driving gear are secured to and rendered vertically adjustable with the bracket C, thus preventing any interruption of the feed when the cutter ring is lowered.

In working the machine it will be occasionally necessary to turn the frame L on its bed plate, which is accomplished by turning the pinion H through the medium of the gearing already described. If this is done while the bed plate is stationary, and the cutting ring in operation, the result will be the gradual withdrawal of the ring from the coal, and the termination of the channel cut. The cutting ring can be inserted to almost its entire extent into the narrow opening which it cuts, and this opening may therefore be cut much deeper than by machines in which narrow cutters are unable to penetrate to the extent of one-half of their diameter. When it is desired to work above the coal, it is necessary to reverse the arm B upon the bracket C, as indicated by B^1, Fig. 879. When it is required to work on a level with the floor of the pit or beneath the coal, a pinion E^2 hung to the arm B may be interposed between the driving pinion E^1 and the rack on the cutting ring, Fig. 880.

Figs. 884 to 887 are Galloway and McPherson's coal-cutting machine. Fig. 884 is a vertical side elevation, partly in irregular section, through the centre of one cylinder A, and the cutting wheel J *j*, and its carrying arm I I′; Fig. 887 a plan; and Figs. 886 and 885 a transverse section and horizontal section taken on the lines 3–3 and 4–4. Two cylinders A, lying at a considerable angle from each other, and the crank shaft B, are erected and worked transversely across the centre of the machine in bearings *b b′*, secured to the side frames C of the carriage. The crank B′ of the crank shaft B is placed and connected to its rods A′, so as to be worked by the trunk pistons *a* of its cylinders A, near the outer bearing *b* of the framing farthest from the face of the cutting Z. The pistons and cylinders are fitted with trunks *a* working out through stuffing boxes *a′* in the front covers of the cylinder next the crank shaft B, in order to give long connecting rods A′ with the shortest possible length of engine frame B″ and carriage C, to the former of which they are bolted down at B^3, as low as they will possibly work well. The slide-valve casings E project outwards, so that the double eccentrics F on the overhung end of the crank shaft B may work the slide valves F′ by their rods F F″. The bevel pinion G fixed near the centre of the crank shaft B gears with the bevel wheel G′ below, secured on the top of the intermediate driving shaft H; this is

carried on I of the carrying arm I′ j, both carried in strong bearings B″ of the engine frame, secured between the side frames of the lower part of the carriage C C′, close to the side next the face of the coal Z to be cut, so that I I′ and J j can swing round equally towards both ends, and cut out under the coal Z to the full length of the arm and radius of the cutter wheel beyond the side C′ of the carriage. The running wheels D on this side of the frame are carried within the frame, those on



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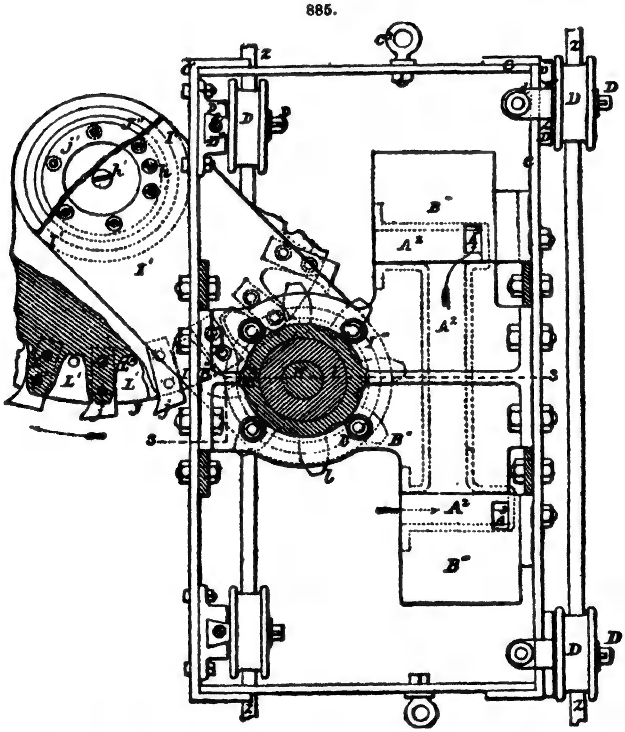
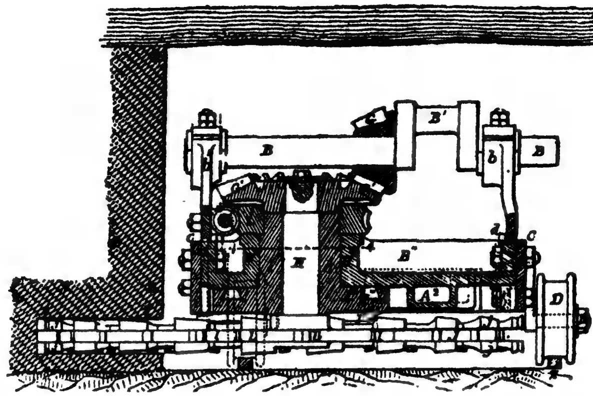


the other side being outside of the frame to give stability to the carriage on its wheels and rails z, the cylinders and engines outside of the frame counterbalancing other weights. The oscillating arm causes the cutting wheel J to cut, by the screw wheel i fixed on the top of I. The cutters being alike at their opposite sides are easily reversed at the ends of the cutting and transverse of the cutting machine, to cut backwards again along the face of a fresh cutting of the coal Z. The cutter wheel J j is made with deep teeth L and recesses, all round the rim at the part where the cutter j and bolts j′ are secured, and of pitch corresponding to the distance between the cutters, the recesses being formed in the spaces between the cutters, so as to be actuated as a spur wheel by a corresponding spur pinion l l′, secured on the lower end of the central shaft H, so as to work into the teeth and spaces L L′, in the wheel J between the cutters j, and are all driven by the bevel wheels G G′, above direct from the crank shaft B B′, of the engine. The diameter of the cutter wheel J and its driving pinion l l′ can be made large enough to cut in under the coal to any depth from the face and side of the machine desired. The large boss J′ is bolted up through the eye J″ of the cutting wheel to a bearing part of the under outer end of the arm I′, so as to carry the wheel thereon by the turned flanges and bearings, which are formed with shallow grooves filled with leather packings at J″, Fig. 887, for retaining oil and maintaining a clean bearing surface, while the centre of this eye is

formed hollow to contain a considerable quantity of oil for lubrication. The arm of the cutter wheel is fixed in the central right-angled cutting position for the long traverse by the dovetailed-headed screw bolts I″, working in a corresponding annular dovetailed groove I‴ in the upper face of the lower heavy flange of the arm I I′, all screwed up tight by their screw nuts round the



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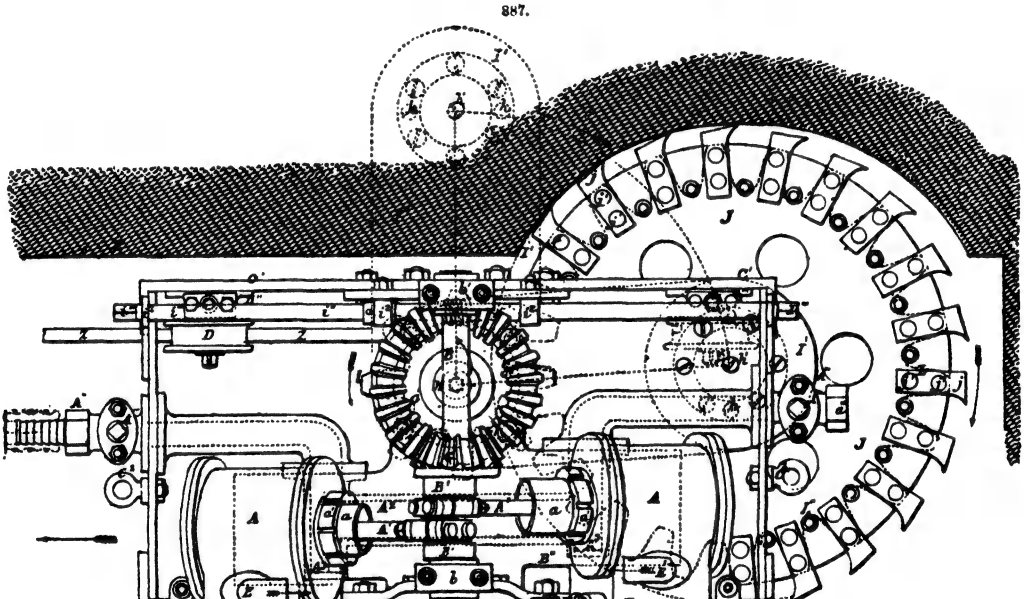
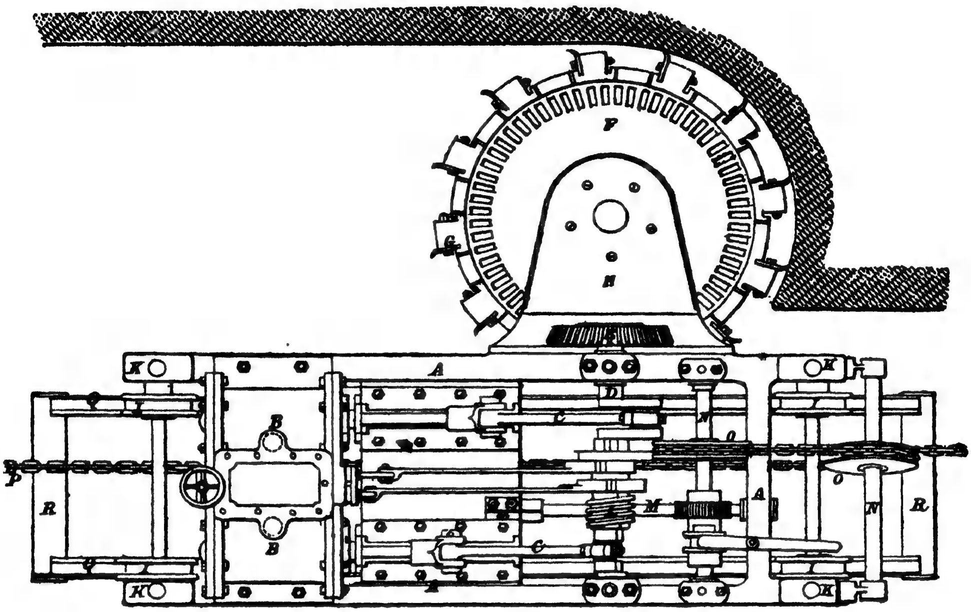


bearing B″ in the frame B, in addition to the holding action of the screw and screw wheel *i i′*, which might allow some little shake or motion of the parts. The engine A B is driven by compressed air, which is conveyed to it by indiarubber pipes attached by couplings to the inlet branches A^2, fitted with stop-cocks A‴, both entering A″, cast in the sole plate B″, leading to the entering ports A^3 of the valve casing E of the two cylinders A, the other branch A″ being closed by its stop-cock A‴ or a blind screw cap at *a″*, each cylinder exhausting the waste air through the outlet discharge branches E′; the engine, gearing, and cutting wheel, driven in the direction indicated by the arrows in Fig. 885, when cutting from right to left along the face cut; and in the reverse direction when cutting from the left-hand end, where the cutting wheel in finishing is swung out under the left-hand end of the carriage, the wheels D D at that end being first removed for the purpose, so as to cut the coal to the end, and make no waste there, and also to leave the cutter wheel J *j* in position ready for a fresh traverse and cut from that end, after reversing the cutters. The engines are reversed by turning round their double eccentrics F on the end of the crank shaft B by the hand lever *f*, re-inserting their fixing pin *f′*, fitted with holding spring or lever *f″*, so as to reverse the working of the slide valves and engine, and cause the cutter wheel, from whatever end of the cutting it is traversed, to discharge the waste coal cuttings which it makes quite behind it. The working parts

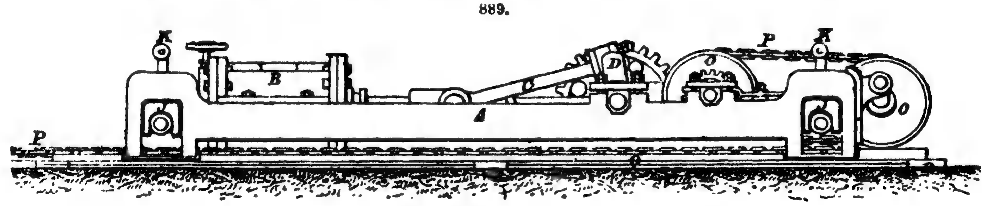
are covered in by a portable metal case resting on the side of the carriage C C′, not shown in the figures.

Rigg and Meiklejohn's coal-cutting machine, Figs. 888 to 890, is made low, being only about 15 in. in height, so as to work in very thin seams, and this it does in many cases without cutting away



any portion of the coal. The whole of the working parts of this machine are so arranged that the cutting wheel can cut in the mineral to the level of the under side of the sleepers supporting the rails on which the machine travels; and it is also provided with means of adjusting it to cut at any angle; while at the same time retaining great rigidity and simplicity of construction. Fig. 888 is a plan of the machine; Fig. 889 a side elevation; and Fig. 890 an end elevation, showing the cutting wheel F, full depth into the mineral, and cutting to the level of the under side of the sleepers R.

889.



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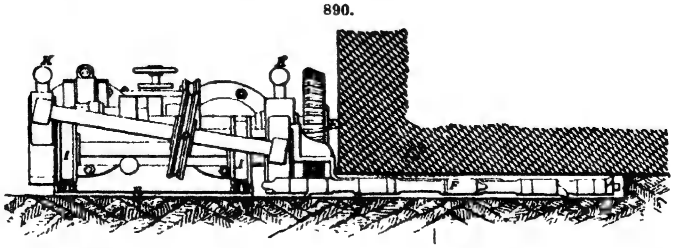


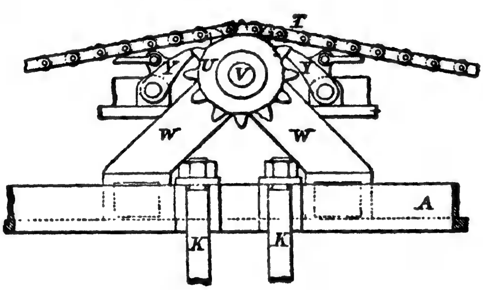
The framework A, is constructed of sufficient size and strength to carry the motive and cutting powers, and is mounted on the four travelling wheels I; the axle boxes J of these wheels are so constructed as to allow of the whole framework, with cutting wheel F, being adjusted to any angle irrespective of the level of the rails and sleepers. At each of the corners of the machine adjusting screws are fixed, which are used for raising and lowering the machine to suit the inclination of the seam. The motive power acts upon the pistons of the cylinders B, which are mounted on A; the power being transmitted to the cutting wheel F, by means of cranks D and bevelled pinion E. The cutting wheel is held in position and supported by the arm H bolted to one side of A; and it is

provided with cutters of a shape suited to the nature of the seam which it is engaged in cutting. The travelling of the machine along the face of the coal, on the rails Q, is accomplished automatically. An endless chain P, is passed round and over the two pitched chain wheels O, and its ends are then firmly fixed at both ends of the face of mineral to be cut; the links of the chain P are caught by the chain wheels O, and the machine is thus made to travel along the coal face as the cutting proceeds. Motion is imparted to the chain wheels O by means of the worm L, the shaft M, and the pinion on the shaft N.

One of these machines in operation at the Hetton Colliery stands 15 in. high from the level of the top of the rails, and weighs about 25 cwt. The average work done by this machine has been 25 yds. an hour, undercutting 3 in. high and 3 ft. 2 in. into the coal. At Penston Colliery, Haddington, one of these machines has been at work for upwards of eighteen months, in a seam varying from 22 in. to 30 in. in thickness. The coal is hard and is worked on the long wall system, in a face of about 200 yds. in length. The average of one month's work in this mine is 130 yds. a shift of nine hours, inclusive of stoppages, or 14½ yds. an hour; the undercut is 3 in. high, 3 ft. into the coal, and close to the floor of the seam. The maximum speed of undercutting is said to be 60 yds. an hour; but this can only apply to a seam in which the holing is very easy.

Alexander's coal cutter is supported by wheels, and carries two cylinders with their pistons, valves, and usual details for obtaining motive power from the action of compressed air. Figs. 891 and 892 are vertical sections at right angles to each other, showing the gearing for obtaining the progressive movement of the machine along the coal face; Fig. 893 is an inverted plan showing the mode of connecting the jib to the under side of the frame; and Figs. 894 and 895 are a plan

891.



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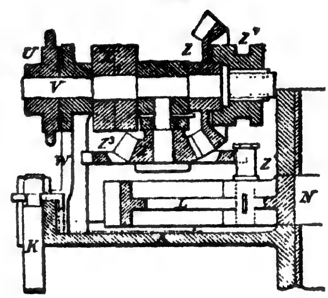

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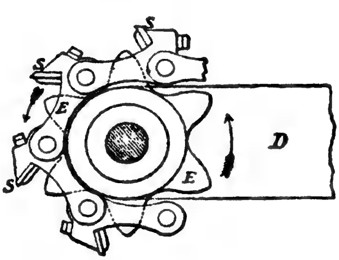

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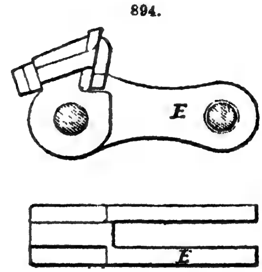
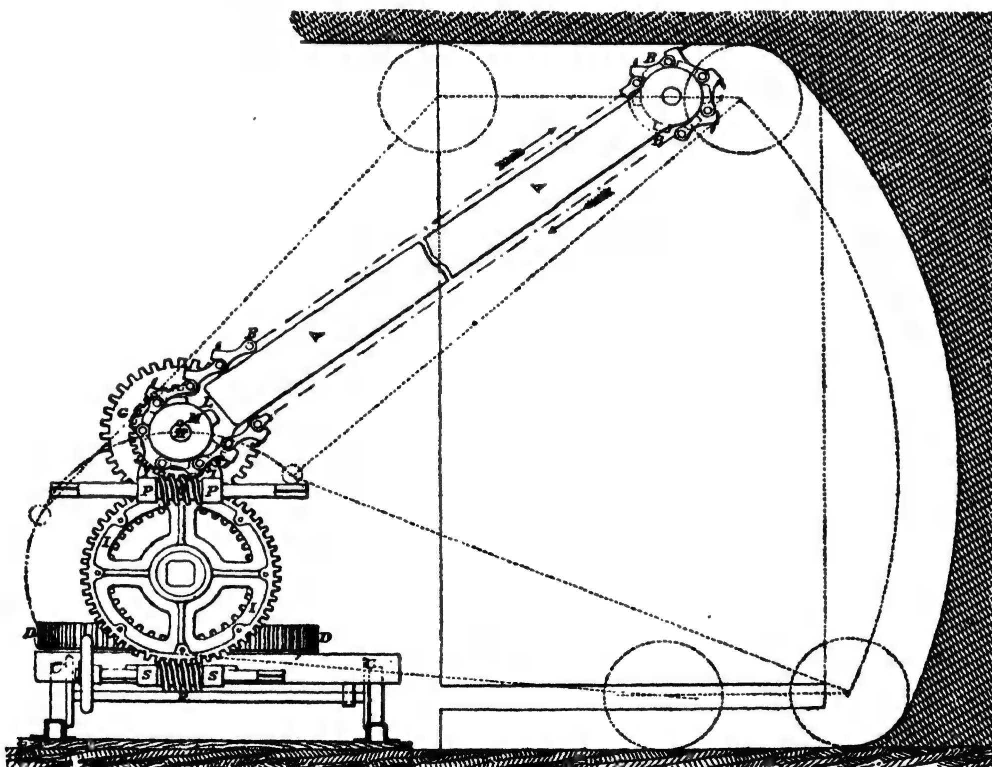


and an edge view of one of the links of the endless chain of cutters. In this machine the jib D is mounted so that it can be swung round in either direction from its usual position, which is at right angles to the coal face, into a position parallel to the face. This enables the machine to be used to cut its way into and out of the coal face without previous undercutting by hand. For this purpose the inner end of the jib D is curved out of the plane of the endless chain, and formed with a large eye, to fit and turn on an annular flange, formed on the under side of the main plate. The jib D is held by an annular plate bolted beneath it to the flange after it is put in its place. The rim is formed with worm-wheel teeth, and the jib is turned as required by means of a worm screw engaging with these teeth, the shaft of the worm being turned with a ratchet lever by hand, or by progressive gearing worked by the machine itself. The jib D is fixed in its right angle position after being entered into the coal face by bolts, for which provision is made in it and in the bed plate. The machine can be placed in its proper working position in front of the coal face without previous holing for the entrance of the jib, when the latter is set lengthways of the machine. The cutter chain is then set in motion, and the jib gradually worked round by the screw acting on the worm-wheel teeth on the eye of the jib, which thus cuts its way into the coal face as it assumes its position at right angles to the face. Whilst the jib is being swung round, the wheel at the corner is removed and a strut fixed between the opposite corner and the roof to prevent the machine from tilting. The driving gearing may be simplified by arranging a single spur wheel and pinion between the shaft of the sprocket wheel which drives the endless chain E and the driving cylinders. The driving pinion and crank shaft are formed in one piece, the crank shaft and the sprocket wheel shaft having bearings in the bed plate A and in a bracket which is bolted down on the plate. The chain link and cutters are arranged so that there may be a cutter to every link E,

instead of every alternate link. Each of these links is made with one end solid and the other formed into two cheeks to embrace the joint tongue formed on the solid part of the next link; the cutter being a short piece of bar steel held by a bolt against a projecting part of the solid end of the link. To effect the progressive motion of the machine along the face as the cutting proceeds, a pitch chain T, Fig. 891, is stretched between fixed points at the ends of the line of traverse of the machine, and with this chain there engages a sprocket wheel U turning on a feed shaft V, which is carried partly by the bracket W and partly by another bracket. This feed shaft, which receives a periodical motion from the driving wheel, has upon it a pair of reversed ratchet wheels, with catches Y for preventing the shaft from turning back. The feed shaft V is turned by means of a bevel wheel Z loose on it, but capable of being engaged with it by the clutch Z′, which can be moved into and out of gear by a forked lever. The bevel wheel Z on the feed shaft gears with a bevel wheel Z″ on a stud fixed to a part of the bracket R, and this last bevel wheel Z″ is formed in one piece with a star wheel Z^3, which is acted on by studs on the driving wheel L, the studs turning the star wheel Z^3 a certain distance each time that one is brought round by the rotation of the spur wheel L.

Figs. 896 to 899 are of an arrangement of this machine for the purposes of vertical cutting. Fig. 896 is partly an end elevation and partly a vertical section at right angles to the face, showing the jib A with its chain of cutters B in the shearing position; Fig. 897 is a vertical section of the machinery; and Figs. 898 and 899 a plan and side view of one of the links of the chain. The parts not shown in these figures are similar to those in the machine for undercutting just described. The horizontal shaft E is placed the long way of the machine, and has keyed on it a spur wheel F, which gears with a spur wheel G on a short shaft H, carried by the crank frame I, K, and is mounted loosely on E. The crank frame is made in two parts I, K, placed one on each side of the pair of spur wheels F G, and bolted together, the wheels F G being between. The outer crank-frame piece I is made with a projecting boss L to receive the eye M of the jib A, which carries the chain

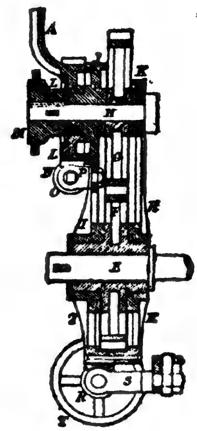


of cutters B; and the spindle H of the spur wheel G projects through this boss L, and carries the wheel N which carries the inner end loop of the cutter chain and drives the chain. The eye M of the jib A is formed with teeth O in gear with a worm P, carried by brackets Q fixed to the outer crank-frame piece I, and by means of a handle applied to the spindle of this worm the jib can be adjusted at any required angle. This crank frame is formed with a toothed arc R, and worm S, carried in brackets T attached to the main framing C, and by means of the hand wheel U the crank frame I, K can be set round to any required position. The cutter holder, Figs. 898 and 899, is similar to that in Figs. 894 and 895, excepting that the cutter V is an oblique chisel-shaped piece of steel, having a socket W formed for it in a projecting part on the link at its joint tongue end, a wedge key X being inserted to keep it in its place. The cutters of the successive

links are in rotation inclined in slightly different directions, so that the full breadth of cut is made by three or four of them, the cutting edge of each being in width equal to a proportional part of the breadth of the cut. This modification of chain-link cutter holder is advantageously applicable when holing as well as when shearing.

In shearing with this machine, the crank frame I, K is adjusted at the outer side of the machine, so that the jib A can be set up from it in an inclined position across the machine, with its outer end extending up to the top of the intended shear cut at the coal face. The cutters are set to move in the direction of the arrows, Fig. 896, from the machine along the upper edge of the jib A, and towards the machine along the under edge of the jib; and as the cutting proceeds the crank frame I, K is gradually turned upwards and over towards the coal face, whilst the jib A is moved on the crank frame in such a way as to keep its outer end at the same height until it has penetrated sufficiently far into the face. The crank frame and jib are then manipulated by means of the worms S and P so as to move the outer end of the jib down in a vertical or more or less curved line until the bottom of the seam is reached; and afterwards the end of the jib A is worked outwards from the interior of the coal face in a direction as nearly horizontal as is convenient.

897.



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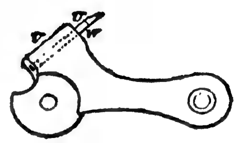

899.

It will be seen that the shearing operation can be

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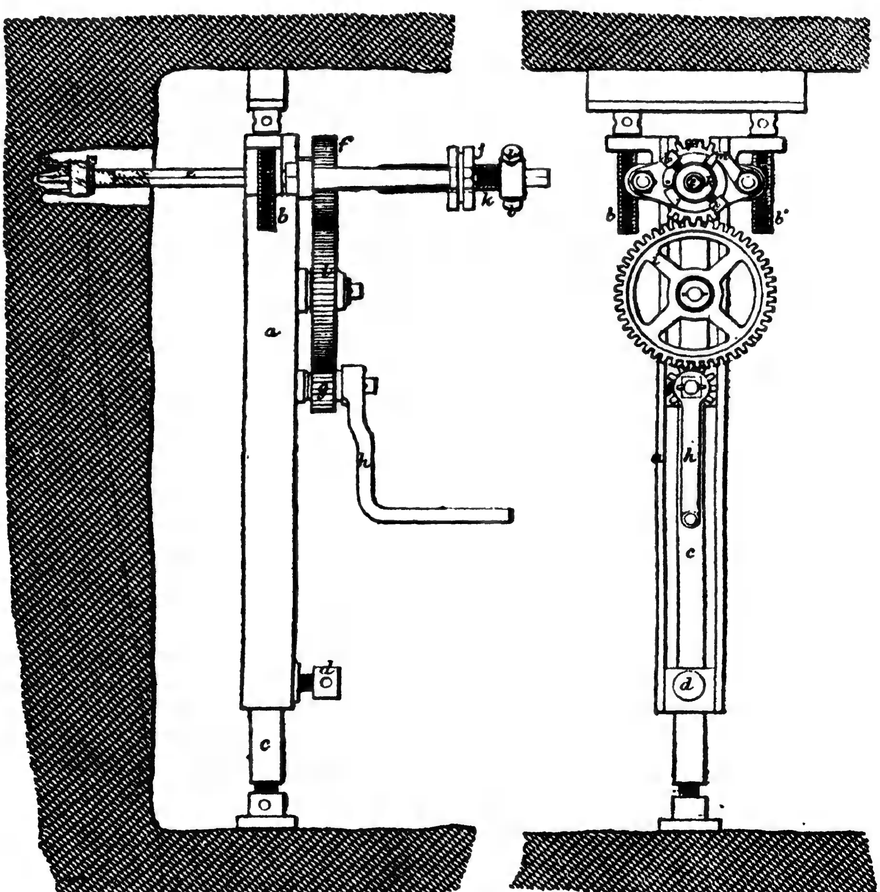


effected whilst the carriage C of the machine is in the position in front of the coal face which it occupies when holing or forming the horizontal cut along the bottom of the coal face. In order, however, to admit of the machine being easily moved into and out of corners and confined places

where it is required for shearing, and along the mine roads, the carriage frame is provided near the middle of each side with a pair of axle studs, on which wheels treading lower than the ordinary wheels at the corners can be placed; when mounted on these middle wheels the machine can be turned in a comparatively small space, and consequently more easily moved in a confined or narrow place.

The object of Dingley and Acker's coal getting apparatus, Figs. 900 to 906, is to facilitate the getting of coal from its natural bed by breaking down after undercutting, or by breaking out from the solid, and to do so by simple hand apparatus, dispensing with power machines and the danger and inconvenience of blasting. For these purposes a hand drilling machine is employed to drill a deep hole in the coal, and afterwards a breaking down tool is used. The expanding tool is made in pieces of about the length of the drilled hole, and of circular form when placed together; in the interior of these pieces are taper grooves to receive a long wedge, which is driven by blows into the pieces, and their expansion thus effected so as to break down the coal.

902.

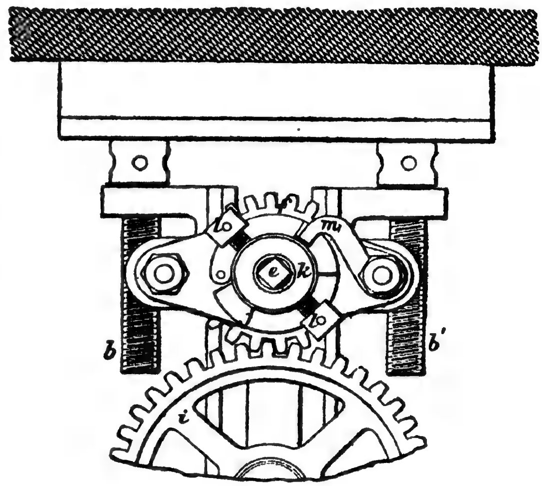
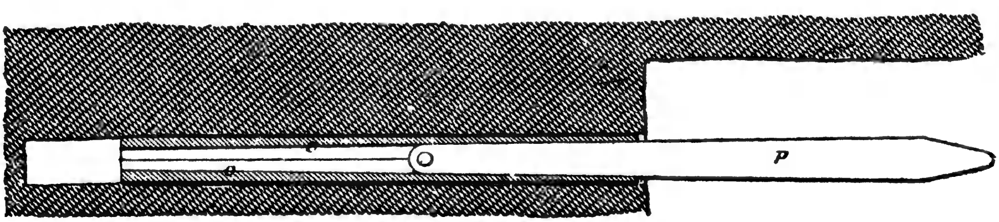


Fig. 900 is a side elevation, Fig. 901 an end elevation of the drilling machine used with this apparatus, and Fig. 902 is an enlarged view of the upper part of Fig. 901; *a* is the framework which is secured in position, between the floor and roof, by the screws *b b'*; *c* is a sliding bar secured to the framework by the set screw *d*, which bar allows of a greater range of adjustment than is permitted by the screws *b b'*. The boring bar *e* is formed of a piece of square iron or steel, and passes through a square hole in the toothed wheel *f*. The driving wheel *g* is operated by the crank handle *h*; motion from *g* to *f* being communicated by the intermediate wheel *i*. This arrangement of gearing allows of the boring bar working close to the roof of the mine. *j* is a nut, through which the screwed sleeve *k* works; the screwed sleeve *k* being attached to and caused to rotate with the boring bar *e* by the set screws *l*. The boring bar *e* can be adjusted to the face of the work, or removed therefrom, by loosening the set screws *l* and sliding the bar in or out; to save time, when the boring bar has worked into the



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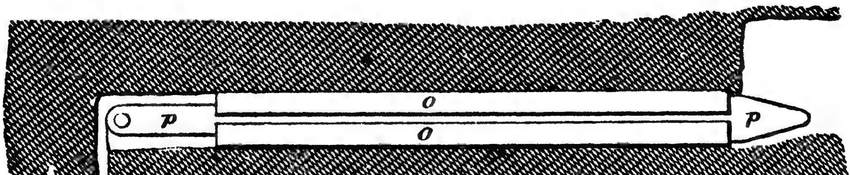

905.

906.

coal the full depth of the screwed sleeve *k*, the nut *j* is formed in two halves, hinged together and secured by the catch *m*, so that it can be opened, the screwed sleeve withdrawn, and the boring bar adjusted without the necessity of screwing the sleeve *k* back again. The end of the boring bar is provided with cutting head *n*, so that the coal is removed in washers or ring. The breaking down apparatus is shown in Figs. 903 to 906; *o* are the expanding pieces, formed with taper grooves in their interior; *p* is the wedge; Fig. 903 is a section through the expanding pieces, showing the wedge inserted; Fig. 904 the wedge driven home and the block of coal breaking away from the face by the expansion of the pieces *o*; Figs. 905 and 906 are end views, before and after driving in the wedge.

Fig. 907 is Hurd and Simpson's apparatus for breaking down the block of coal cut out by the heading machine, and for removing the thin layers of coal left by the machine between the roof and floor of the heading and the hole cut out. This apparatus consists of a cast-steel wedge or shovel X, which is forced forward by the screw Y; this screw is turned round by the lever Z and catch Z' acting on the toothed wheel V, being in fact an adaptation of the ordinary ratchet brace. The catch

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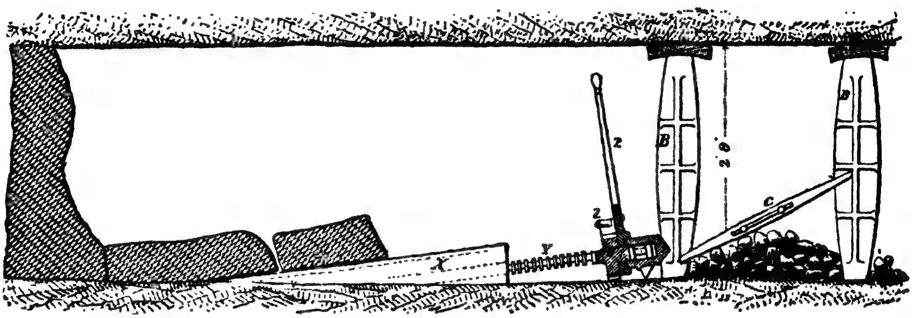
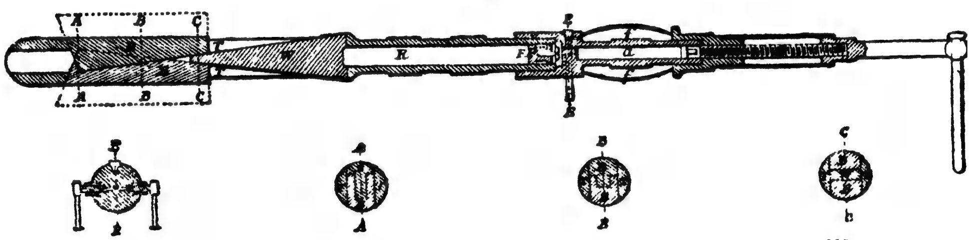


is reversible, the end of the screw Y working in a socket which abuts against one of the cast-iron props B; the adjustable stay C serving to increase the resistance to the screw Y. The wedge shovel X is 14 in. wide, and is partly double wedged in cross section to prevent it slipping sideways when the power is applied; the full length of the wedge is 24 in., with a taper of 6 in. and a screw traverse of 20 in.; all the working parts being made of steel.

Fig. 908 is a longitudinal section of J. Grafton Jones' hydraulic wedge for getting coal, and Fig. 909 a cross section on the line E E; T are tension bars which enclose the inclined steel

908.



909. 910. 911. 912.

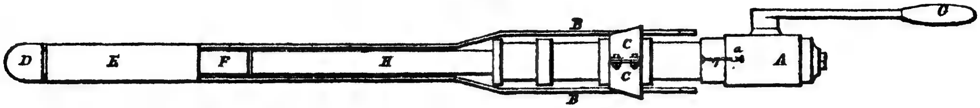
pressing blocks B; W is the wedge; R the ram; P is the piston carrying the cup leather; Y screw plugs; a is the screw pump cylinder; D is the screw; and f is the reservoir of water or oil. The pressing blocks B are fitted one into the other, in the cross sections Figs. 910 to 912, in order to increase the amount of expansion; by this arrangement the expansion obtainable, or the distance travelled by the pressing blocks when the wedge has been driven home, is equal to the diameter of the hole into which the instrument can be put. This form of pressing block renders the use of split wedges unnecessary, as the expansion is obtained with one wedge, a point of great importance, for the labour and delay caused when it is necessary to introduce additional wedges in order to obtain the requisite degree of expansion are considerable. The movement of the pressure blocks, shown by the dotted lines in Fig. 908, is parallel to the axis of the machine, so that the whole length, and not one corner only, of the blocks is pressed against the coal. The diameter of the main cylinder is 3½ in., and the expansion of the blocks B 3½ in. The distance travelled by the wedge is 14 in., the power of the ram being multiplied by 4; the area of the piston P is 2 circular inches, and that of the screw pump D one circular inch, multiplying the power of the screw by 2. The screw has five threads to the inch, and the handle by which it is turned is 2 ft. long; thus the leverage of the screw is $24 \times 2 \times 3\frac{1}{7} \times 5 = 755$. If therefore the weight or power applied to the handle be equal to 1 cwt., the pressure on the pressing blocks will be equal to $1 \times 755 \times 2 \times 4 = 6040$ cwt., or say 300 tons.

This machine has been in use at the Kiveton Park Colliery, South Yorkshire, where the coal is very hard. A hole is first drilled about the middle of the seam, and exactly on the end; into this hole the machine is placed, and by the lateral movement of the pressing blocks the coal is split along the line of cleavage; blocks of coal 4 yds. long and 4 ft. wide being got at one operation. The coal is about 5 ft. thick, thus about 8 tons are got with one application of the machine; and this coal is in such a form that it can easily be broken up with a bar for loading into the tubs. In breaking down coal which has been previously holed no difficulty is experienced; and for this work machines are made as small as 2 in. in diameter, and weighing but 40 lb.; although with one of them a pressure of 200 tons can be put upon the mineral to be broken.

Bidder's coal breaker, Fig. 913, consists of a small hydraulic press A of 15 tons power, and weighing about 60 lb. To this press is attached a pair of steel tension straps B, bent in the form of a tuning fork, and connected to the press by the collar C. At the end of these straps is first

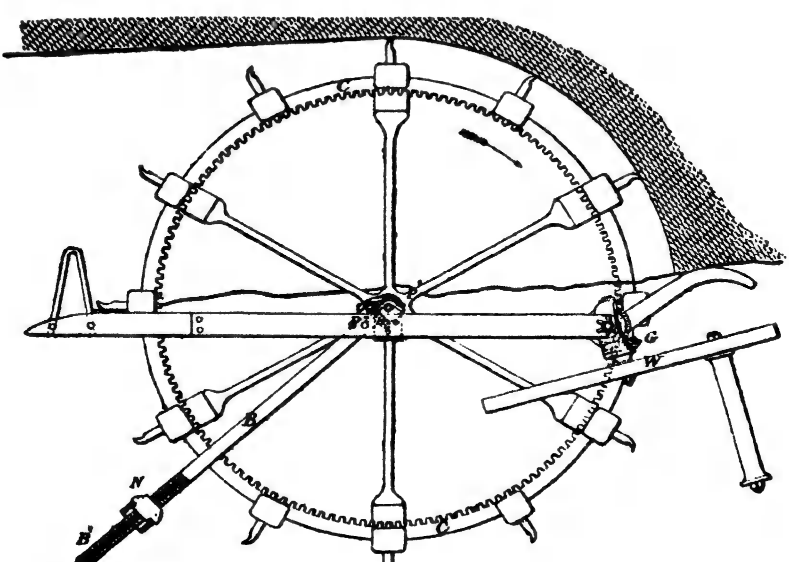
placed a clearance box D, about 4 in. long, and upon each side of the straps expanding pieces E, made of steel and 15 in. long, which exert a pressure at the sides of the hole. The points of a pair of twin wedges, 15 in. by 3 in., and forming one wedge, are then inserted in the expanding piece, and the machine is fixed in the hole. The hydraulic press having been charged with three pints of water, which may be used over and over again, is then worked by means of the small handle G, and the ram H forced out from the cylinder, thus driving up the pair of wedges between the expanding

913.



pieces, and giving a lateral expansion of about 3 in. This not being in all cases sufficient to bring down the coal the press is withdrawn, and the relief valve *a* opened, thereby allowing the water to return to the reservoir. A second wedge is then inserted between the two twin wedges by means of a small rod, five-eighths of an inch in diameter, and the press being again connected this wedge is driven home. By this means an additional expansion of 3 in. is obtained, making a total expansion of 6 in., which in most cases is found to be sufficient; but a third wedge can be applied if necessary, and the expansion thus increased to any reasonable extent. In this manner as much as 10 or 12 cwt. of coal have been brought down in ten minutes. The drilling apparatus consists of a screw 4 ft. long by 1½ in. diameter, to the end of which is attached the drill. The fulcrum for taking the resistance of the screw is obtained by inserting a bar of iron in the coal at the side of the place selected for the hole which the machine has to drill. This small aperture is made by punching with the ordinary instrument a hole 10 in. deep and 1 in. in diameter, and the time occupied in making this preparation is usually about four minutes. The small bar for taking the resistance of the screw is then inserted, and it may either be fixed at the side or in the face of the coal, as the case may require. The screw is then adjusted to this bar, and the drill driven in the coal by a man turning the handle at the end of the screw. The time occupied in drilling this hole for the machine, 3 in. in diameter and 3 ft. 6 in. deep, is from ten to fifteen minutes, according to the hardness of the seam. If it is necessary to drill the hole in such a position that the rotary motion of the handle by which the screw is propelled cannot be obtained, a ratchet may be used, so that under any circumstances no difficulty can be felt in procuring the required motion.

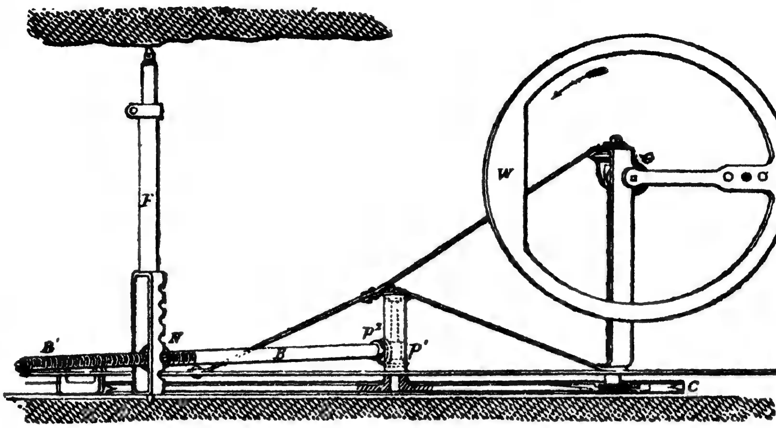
At a trial of this machine in a pit at North Staffordshire, in a heading in the 8 ft. Banbury seam, under ordinary working circumstances, the hole for the machine was drilled, and about 4 tons of coal brought down in twenty-five minutes. It was reckoned that to have brought down the same amount of coal by blasting would have required 1 lb. of powder and have taken one hour to drill the hole for the charge; the machine thus showed a saving of the whole value of the powder and thirty-five minutes in time.



Lilienthal's hand-power coal-cutting machine, which has been used with satisfactory results in different mines on the Continent, is of simple construction, and can easily be moved by two men and erected in narrow and low headings. Fig. 914 is a plan of this machine, and Fig. 915 an elevation, partly in section. The cutter wheel C is made with internal cogs, and is driven by the pinion P, to which motion is imparted by means of the bevel gearing G and flywheel W; the

wheel W being turned by one or more men, according to the hardness of the seam. The forward motion of the cutter wheel C, in order to keep the cutters up to their work, is obtained in the following manner;—A bevel pinion P′ is made fast upon the axle of the cutter wheel C, and this pinion drives a second bevel pinion P″ fast on the bar B, the end of this bar B is screwed and turns in the fixed nut or collar N, which is attached to the fixing bar F; and so by the revolution of

915.



the bar B, the cutting wheel C is gradually and regularly driven forward and kept up to its work, at the same time that it is guided by the cut already made in the coal. The amount of the forward motion which is given to the cutter wheel at each revolution depends upon the relative diameters of pinions P′ and P″, and the pitch of the screw B′; for coal of average hardness and quality a forward motion of the cutting wheel of about half an inch a revolution has been found to answer best. The amount of work done by this machine averages about 18 sq. ft. of coal cut an hour by two men.

The cost of conveyance of the coal from the working places to the shaft may determine the profitable working of a seam. The term haulage is applied to this operation, and includes the loading of the coal into the sledges or tubs, and the dragging of these to the nearest horse-road, described as putting in some districts and as carting in others. Haulage comprises putting the coal to the road, conveying it along the road to the main levels, and conveying it again along these levels to the shaft. In each of these stages different conditions will be encountered and different means employed.

A principle to be observed is to avoid all unnecessary shifting of the coal. When the coal is once loaded into the tub at the working face it should not again be touched until it is shot out at surface.

The conditions involved are the inclination of the roads, which may be in favour of or against the load; the regularity of the inclination and the direction, for a succession of elevations and depressions in the surface of the roads, and the existence of curves unfavourable to the traffic; the state of the surfaces over which the wheels of the tubs run, the even and firm laying of the tram rails, and their preservation in a state of efficiency; and the provision of suitable and convenient shunts. The operations of putting the coal along the working face constitute the first stage of the labour of haulage.

The mass of coal thrown down at the working face by the getters, is broken up with sledge hammers by the loaders into blocks of a size capable of being handled, care being exercised to make as little small coal as possible. The blocks are lifted by hand into the vehicle. It is the duty of the loader to reject all the impurities accompanying the coal. As, however, he gains by including the impurities with the coal, supervision and checks are needed. The supervision must be exercised in the working places, and the checks applied at surface. The loaders place a number or a metal ticket, called a token, upon each load sent away. On arriving at bank, the load is weighed and entered in a book according to the number it bears.

When the coal has been loaded, the tub has to be dragged or put to the nearest road. Sledges were, and are still, used for this purpose. The form varies widely, but it consists essentially of a wooden box set upon two wooden runners. As a vehicle for the conveyance of coal, the sledge possesses some advantages and numerous defects. It may be made very low to suit the requirements of thin seams, costs little, and may be used without a specially prepared road. But it requires great force to be dragged over even a tolerably smooth floor, and its small capacity necessitates the employment of a great number of putters.

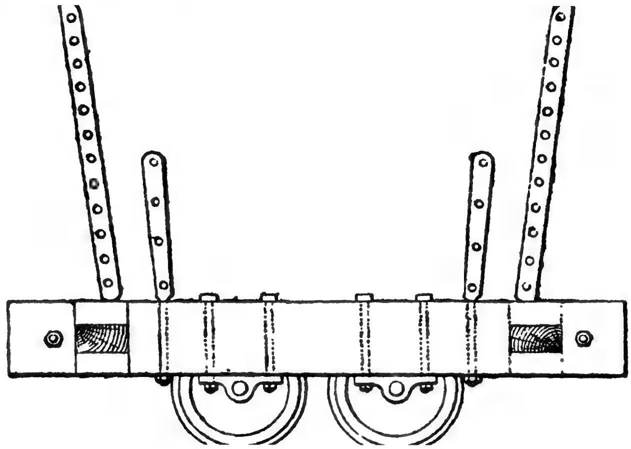
Instead of the sledge, the tub is now generally adopted. It consists of a rectangular box built on a stout oak framing, and carried upon axles and wheels. The capacity varies generally from 5 to 8 cwt. The wheels are flanged to run upon bridge or T rails, and vary in diameter from 7½ in. to 15 in., according to the requirements of the seam and other circumstances. Tubs of wrought iron are also largely employed; of these, Figs. 916 and 917 afford typical examples, that in Fig. 917 being fitted with a hand brake.

Wherever the circumstances are favourable, tram rails are laid along the face. A tramway in such a situation is of a temporary character, and the easiest method of laying the rails is

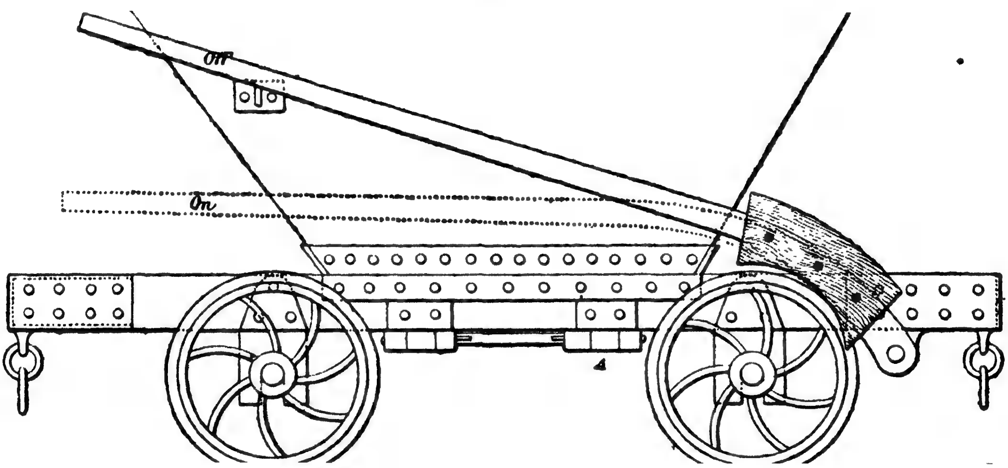
desirable. One of the simplest tramways consists of half-round fir sleepers, provided with two notches into which the rails are laid, and held in place by means of wedges driven in on the inside of the rail.

The subject of the wheels and axles adapted to tubs and colliery trams will be found treated in this Supplement, under the head of Axles.

916.



917.



In driving the roadways, undulations in the floor should be avoided. The form of the rails, and the means employed for connecting the rails to the sleepers, are the same upon important underground engine planes and upon surface railways, the only difference being in the dimensions of the material used. On the less important ways, simpler means of connection, and sometimes simpler forms of rail, are adopted.

The rail used in the edge-rail system is a flat iron bar, from 1¼ in. by ½ in. to 2¾ in. by ⅝ in. in section, according to the weight of the traffic, and upon the edge of this rail the wheels of the tubs run. The rail is fixed to the sleepers by a wedge.

A common form of rail laid in the main ways is the ordinary double-headed rail. This form satisfies the requirements of underground lines, since it is of light weight, is laid upon transverse sleepers, and may be easily fixed in position. When the line is to be permanent, it is laid with cast-iron chairs in the manner adopted upon ordinary railways; but in less important ways, the rails may be spiked down to the sleepers. Bridge rails possess the advantage of being the lightest form obtainable, but require longitudinal sleepers, which in a mine are objectionable. Bridge rails have been laid upon transverse sleepers, but their section is unsuitable for that kind of support. The Vignoles rail has been adopted on underground lines with satisfactory results. When the floor is weak, short rails should be used for the purpose of reducing the length of line

necessary to be pulled up and relaid. In places where the floor is very soft, it will be well to distribute the pressure by placing longitudinal timbers beneath the cross sleepers. The weight of the rails used of any given section will vary with the capacity of tubs, and also with the distance of the sleepers apart. Generally this distance will be about 2 ft., or 2 ft. 3 in.; if spaced more or less widely than this, the weight of the rail for a given load must be increased or diminished in a proportionate degree. On the principal engine planes, the weight of the rails will vary generally between 18 lb. and 24 lb. to the yard; on the secondary roads, a considerably less weight will be found to be sufficient.

In the construction of undergound railways, the joints which claim special attention are the junctions of the various lines with each other. These junctions are far more numerous than on surface railways, and take place at sharper angles. When one line enters another at a small angle, the mode of effecting the junction is similar to that adopted on surface lines, slight differences of detail only being made in favour of simplicity.

The roads of a mine frequently intersect each other at a great angle; and when the junction has to be effected under such conditions, other means have to be adopted, consisting generally of a fixed table, upon which the tubs are turned, by being lifted at one end and carried, or by being dragged round. The table or platform is constructed of stout planking, carefully laid, and covered with iron plates, to diminish the friction, and to lessen the wear and tear. The chief points requiring attention are to lay the floor evenly, and to give the structure sufficient stability to resist the somewhat violent strains thrown upon it. The ends of the rails are brought upon the flooring, and made to curve outwards; and between these curved portions ribs or raised guides, curved in the contrary direction, and brought together in a point, are placed; the object of this arrangement is to facilitate the entrance of the tubs. A road upon which the traffic is effected by the full tubs causing the movement of the empty ones is called a self-acting plane. An inclination of 1 in 36 is the limit, below which the plane ceases to be self-acting, and to attain so low an inclination as this the road and the tubs, as well as the apparatus employed therewith, must be maintained in a perfect condition. Practically it may be considered that 1 in 30, or a little more than 1 in. in a yard, is the least inclination that will render a plane self-acting. As the inclination becomes greater than this, a brake will be required to absorb the excess of force acting in the descending load.

In plan, a self-acting plane differs but little from the ordinary roads; it requires, however, to be somewhat more strongly constructed. Generally a double line is laid throughout the length of the plane, and each line receives alternately the loaded tub, but a single line of rails can be worked on this system with a pass by. The loaded tub in its descent forces the points back, and the empty tub thus finds the way prepared for the ascent. This mode of laying out the line allows the breadth of the road to be reduced.

The only mechanism required to work a self-acting plane consists of a reel, sheave, or drum, around which a rope or chain is passed, and upon which is set a brake to control its motion. The apparatus may be made to revolve about either a vertical or a horizontal axis, the latter arrangement being more common. In the former case, only one rope is used, which is passed round the sheave, one end being attached to a tub at the bottom of the plane, and the other end to a tub at the top of the plane. In the latter case, either two ropes coiling in contrary directions may be used, or a single rope sufficiently long to be passed several times round the reel. In some instances an endless rope has been employed, which is made to pass over a pulley at the bottom of the incline, and kept in a state of sufficient tension by means of a counterweight connected to the pulley with the endless rope, which requires the tubs to succeed each other with great regularity; the full tubs descend on one line of rails, and the empty ones ascend on the other. Whatever the arrangement adopted may be, a powerful brake must always be provided. This brake may consist of a segment of wood fixed to a lever, and arranged to be readily brought into contact with the periphery of the sheave. To obtain greater power, compound levers are employed, and the same object may be attained by means of an iron band enclosing the whole of the periphery, and worked by a system of jointed levers.

In order that the brake may be capable of controlling the motion of the load, as well as that of the sheave or reel, it is necessary to arrange the rope in such a way that it cannot slip. With the horizontal reel this may easily be effected by passing the rope a few times round it. But with a sheave turning about an axis that is perpendicular to the plane this expedient cannot be so readily adopted. One turn round a sheave having the ordinary kind of groove would be insufficient to prevent slipping. In such a case the groove is made conical, so as to grip the rope, or a clip pulley is used. Another method consists in passing the rope several times round the sheave, and providing an arrangement by which the friction of the several turns of the rope against each other is avoided. The arrangement is merely the addition of one or more parallel grooves to the sheave, which is then put in relation with another sheave of any diameter provided with one groove less. The rope is wound and unwound upon this sheave regularly, as upon one of the ordinary kind.

The friction of the rope upon a self-acting plane is considerable; and this friction not only absorbs the motive power, but causes a rapid wear of the rope. This is reduced by means of friction rollers, placed at short intervals apart throughout the plane, to prevent the sag of the rope from causing contact with the ground. These friction rollers should be of a considerable diameter relatively to their gudgeons, which should be kept well greased. The details of the method of working a self-acting plane vary somewhat, according to the inclination of the plane, the number of the points at which it receives the tubs, and the number of tubs let down at one time. When the inclination is moderate, and the tubs are despatched from the top of the plane, each man, as he arrives with his loaded tub, immediately attaches it to the rope and runs it on to the rails of the plane. The brakesman does not allow it to descend until he has received a signal from the bottom, informing him that an empty tub has been attached to the other end of the rope, when he releases

the brake and the load descends, bringing up the empty tub. Continuous systems of working by endless ropes have previously been described in this Dictionary, under the head of Haulage.

When the coal has been brought to the bottom of the shaft, it has to be lifted or wound up to bank; and to effect this the tubs are placed upon a platform termed a cage. The various forms and arrangements have been fully described at p. 266 of this Supplement.

The introduction of cages moving between guides, combined with the adoption of steam engines of great power, have rendered it possible to attain a high speed in the shaft, and to raise large quantities of coal in a given time. As the entire output of a colliery will be limited by the means available for raising the produce through the shaft, it is desirable to provide for future contingencies.

It was formerly the custom to tip the coal as it arrived at the shaft into tubs or buckets, in which it was raised to bank. These being allowed to swing loose in the shaft, rendered it impossible to wind at a high speed; and it was necessary to adopt some arrangement to prevent the ascending vessel from coming into contact with the descending one, when two were used in the same shaft. This system of winding was very slow and insecure, and by the vessel striking against the sides of the shaft, both it and the rope were speedily destroyed. The system is still in use in Belgium, and partially in Staffordshire, where the coal is raised upon skips. The necessity for a better system of winding led to the adoption of cages moving between guides. These cages are of iron, made to contain one or two or more tubs. The tub is run on to the floor of the cage at the bottom of the shaft, and off again when the cage has arrived at surface, so that the transfer of the load from one receptacle to another is obviated. The cages are made to run between guides, that they may be raised and lowered at a high speed with safety. In some pits the load is raised with a velocity of 20 ft. a second. In Staffordshire, instead of using cages, the corves are suspended directly from the rope, and raised in that manner in the shaft. The corves differ in their construction from tubs, and are a platform carried upon wheels with two or three large iron hoops. To load these skips, as they are called, a quantity of coal is stacked upon the platform, and the largest hoop is then placed over it to keep it in position. A second quantity is then stacked up, and a second hoop of a somewhat smaller diameter placed over it. These operations are repeated with hoops of smaller size, until the pyramid of coal has attained the limit of height allowed. The mass is further held together by the four chains by which the skip is suspended from the drawing chain. The load is then drawn by a horse to the bottom of the shaft, where it is attached to the drawing chain. On arriving at surface, it is drawn from over the shaft upon the landing, or on to a sliding platform run over the shaft mouth, upon which platform the load is then lowered. The loaded skip having been run off, and its place supplied by an empty one, the latter is raised sufficiently to allow the platform to be withdrawn and then lowered into the shaft. The head-gear of a shaft has been described. It consists of a pulley frame, constructed either of wood or of wrought iron, carrying a pulley, or more frequently two pulleys, over which the rope suspended in the shaft is passed, and led thence to the drum of the winding engine. These pulleys are provided with a round or a flat groove, according to the form of the rope used, and are made of a large diameter in order to avoid giving a quick bend to the rope.

The essential parts of a pit-head frame are the legs or uprights, upon which the pulleys rest, and the spurs or inclined supports which are set on the side of the legs next the engine. All other parts of the frame are auxiliary. The uprights are intended to resist the vertical strains, and the spurs the oblique strains.

The wood used in the construction of pit-head frames is usually pitch or Memel pine. It is essential to stability that all the chief parts of the structure should be set upon the same wooden framing. This wooden framing consists of sills strongly jointed and bound together, upon which the legs and spurs are set by means of cast-iron sockets bolted down to the sill. The double tenon joint is generally the most suitable in such structures, and it may be rendered secure by an iron bolt passing through each tenon. After the joints have been properly fitted, they should be well covered with red lead. The legs of the frame are slightly inclined to each other towards their summits, and are braced together. The spurs are also in some instances braced to the legs, or made to butt against the engine house. In order to obtain the greatest height possible, with timber of a given length, the cap or framing carrying the pulley is placed above the uprights and back-stays. As it is necessary that ready access should be had to the pulley, it is usual to provide one of the back-stays with steps. Iron pit-head frames are also much used, and have been already referred to at the commencement of this article.

The pulleys used on pit-head frames are of iron, and vary in diameter from 10 to 20 ft. When wire ropes are used, the pulley must be of a large diameter, to avoid straining the metal by too sharp a bend. Formerly pit-head pulleys were constructed wholly of cast iron, and this material is still used in the South Staffordshire district, where heavy drawing chains are employed with pulleys of small diameter. But generally this system has been abandoned for the compound system, in which the central boss and the rim are of cast iron, and the arms of wrought iron. The rim of the pulley is grooved to receive the rope, and the bottom of the groove is made either circular or flat, according as round or flat ropes are to be used.

Hemp was formerly the only material employed in the manufacture of ropes; later, aloe fibre was adopted, and these two materials are still commonly used. The strength of ropes made of aloe fibre is slightly greater than that of hempen ropes, and their durability is superior, but they are specifically heavier. Iron wire has been adopted as a material for ropes, several wires of the toughest iron being twisted together in the same manner as the strands of the hemp ropes, but the degree of the twist is less in the former than in the latter. Theoretically, a wire rope will best resist the strains brought to bear upon it, when all the wires of which it is composed are parallel to one another; but practically, by reason of the flexibility and extensibility required, the strength of a wire drawing rope is found to be greatest when the strands are arranged spirally as in the hempen rope. In the wire rope, the weight of each unit of length is, for a given strength,

considerably less than in the hempen and aloe-fibre ropes, and the diameter is also reduced in a like degree. The flexibility however is less, and for that reason, pulleys of a larger diameter have to be employed. The transition from iron to steel was easy, and the most recent ropes are of this material. The greater tensile strength of steel allows the diameter of the rope to be still further reduced, so that the weight a unit of length has again been lessened.

In flat ropes it is supposed that the several wires of the rope are more evenly strained than when arranged spirally. This result may be regarded as more than doubtful. If the face of the pulley is not perfectly flat, the rope must be irregularly strained. To prevent this, each strand is made as nearly as may be identical, and they are used in even numbers. The direction of the twist is contrary in each pair, to counteract the tendency of the twist to come out under the action of the load. In winding, the flat rope is made to lap over itself upon the drum, so that the diameter of the latter is practically increasing or decreasing during the operation of winding. An advantage of this overlap of the rope is that the latter is kept constantly in the same vertical plane. The flat rope has not been regarded favourably by mining engineers.

The subject of the strength of ropes has been dealt with in this Dictionary under the proper heading, and that of strength of materials. Winding engines also will be found treated in this Supplement under the separate heading.

Round rope is wound upon the drum in parallel coils, and in some instances it is made to rise and return upon itself on cylindrical drums for the purpose of diminishing the length of the latter; this arrangement is unfavourable to the durability of the rope. When the drums are conical, overlap is impossible, and the necessity for it does not exist. A flat rope is always wound upon itself, so that its coils are all in the same vertical plane.

When both portions of a round rope are wound upon the same drum, the length will be that required by a single rope, since one portion is being unwound while the other is being coiled upon the drum, so that the sum of the lengths coiled at any given moment is equal to the length of one portion of the rope. In such a case, one portion of the rope is wound over the drum, and the other portion under the drum. As both portions are wound over the pulley, one is thus wound in contrary directions, a circumstance unfavourable to its durability. The evil is remedied by the use of two drums revolving in contrary directions, an arrangement which allows both portions of the rope to be passed over the drum. Usually a notch or a groove is provided on the drum to receive the end of the rope, which is held in by wedging. To avoid bringing the strain of the load upon this fastened end of the rope, the length is always regulated to leave two or three coils upon the drum when the cage is at the bottom of the shaft.

In arranging the length of the rope, the two portions are so proportioned that when one cage is resting at the bottom of the shaft, the other is resting upon the keeps at the top. A slight excess of length is given in order that the operation of raising the top cage a little above, and the lowering it upon the keeps may not affect the bottom cage. In determining the length for a new rope, a little allowance should be made for stretching. It may happen that in consequence of the working being directed to a higher seam, or from some other cause, the rope is found to be too long; or in consequence of a defect having to be cut away, it may become too short. In such cases, as in that of putting up a new rope, it becomes necessary to proportion the lengths as required, that is, a number of coils will have to be taken up or let out from the drums. One method of doing this is the following: the end of one rope is let down to the level of the pit mouth and the excess of the other is measured in the shaft; the former is then taken off the pulley and wholly wound upon the drum, and the end attached to it, after which the drum is turned until a sufficient length of the latter has been removed to equal the excess of length in the shaft. The first having then been replaced upon the pulley, the two ends will arrive simultaneous at the points required. If one of the two ropes requires to be lengthened, these operations will, of course, have to be reversed. By reason, however, of the great weight of the rope, its removal from the pulley offers considerable difficulties; to escape these difficulties, where two drums are used, another method has been adopted, which consists in providing an arrangement by means of which one of the drums may be made loose. With this arrangement, the relative lengths of the ropes may be readily adjusted.

The position of the drums is a matter of importance. Relatively to the engine, they may be placed with their axes in the horizontal plane passing through the piston rod, or they may be placed above the cylinders with their axes in the vertical plane passing through the piston rod. Relatively to the pulleys, the level of the drums should be so adjusted that the inclined portion of the rope shall not make a very acute angle with the vertical portion; hence the higher the pulleys, the greater should be the interval between the drums and the pit mouth. Too great a distance is, however, objectionable, by reason of the sagging and swaying of the rope. The best arrangement, where it can be adopted without difficulty, consists in erecting the drums at a higher level than the pit mouth. This is one of the advantages obtained by placing the drums over the steam cylinders. An essential condition to be observed is to place the drum and its corresponding pulley in the same vertical plane, and strictly perpendicular to their axes of rotation. A slight irregularity in this respect, by forcing the rope to deviate from one side to the other, gives rise to considerable lateral friction, which tends to rapidly destroy the rope.

The means of regulating the load comprise the counterweight and the conical drum. The regulating effect of the conical drum is more or less fully obtained, when a flat rope is used, by coiling the rope upon itself, to which the virtual diameter of the drum is made to vary.

The counterweight usually consists of a number of heavy iron links, suspended in a pit or well from 30 to 50 yards deep. To these links is attached a rope, which is fixed to the drum shaft. The length of the balance chain is equal to the depth of the pit in which it hangs, and it is connected to the drum shaft in such a manner, relatively to its length, that when the drawing ropes are at the starting point, that is, when one cage is at surface and the other at the bottom of the shaft, its whole length is hanging in the pit. The rope by which it is wound up is also arranged so that the whole of the balance chain may rest upon the bottom of the pit when the ascending and the

descending cages arrive at the same point in the shaft. This rope is made to pass over the drum shaft in a direction contrary to that of the drawing rope which it is intended to counterbalance. At the moment of starting the engine, the whole of the links are suspended, and these, by their great weight, hold the drawing rope in equilibrium. As the latter ascends and is diminished in weight, both by reason of the reduction going on in its own length, and of the increase taking place, at the same time, in that of the descending rope, the links are being deposited at the bottom of the pit, and the whole of the links will be resting upon the bottom when the cages meet in the shaft, at which moment, the ascending and descending ropes balance each other. From the time when the cages pass each other, the weight of the descending rope preponderates, and this preponderance goes on increasing until the bottom of the shaft is reached. But when the descending cage passes the ascending one, the counterbalance chain is again being wound up, this time in the contrary direction, and as it is raised link by link, its weight counteracts the preponderating weight of the descending rope. This system of counterbalancing, if it does not give perfect uniformity, solves the problem of regulating the load with sufficient completeness for practical purposes. The weight of the balance links must, of course, be proportioned to that of the rope, account being taken in the calculation of the diameter of the pulley or drum upon which it is wound. This diameter is related to the depth of the pit or well in which the chain hangs. The pit is generally situate on the side of the drum farthest from the shaft. Sometimes, instead of the chain, a heavily loaded tub, or truck, is used as a counterweight. In this case, the tub is made to run upon inclined rails. The inclination of the road is made to vary so as to be sharp near the upper end and flat at the lower end, for the purpose of obtaining a constantly increasing or diminishing resistance. During the time of drawing a load, the tub runs twice over the road, first descending and then ascending. Thus the force of traction exerted by the tub upon the rope to which it is attached is greatest at the moment of starting, nil at the end of its course when the cages are at the same point in the shaft, and greatest again when the cages have reached the landing place. By carefully determining the curve required, the counterbalancing of the rope may be, in this way, very completely accomplished, and often more easily, and at a less cost than by means of the chain. To determine with rigorous accuracy the curvature of the line upon which the tub is to run, would require the application of the higher mathematics. But in practice, rigorous accuracy is not needed, and even if arrived at by calculation, it could not be obtained upon the ground.

The other means of regulating the load by means of a conical drum is not so good an arrangement as the counterweight; but it possesses the advantage of less complication. In practice, a common size of conical drum is 16 ft. at the smaller end and 20 ft. at the other. Large conical drums are sometimes provided with a spiral channel for the reception of the rope, the object being to prevent the rope from slipping.

In considering the ventilation of a coal mine, it must be remembered that the efficient ventilation of any space to be occupied by human beings consists in the regular supply of so much fresh air that the impurities occasioned by the several sources may never exist in proportions injurious to health. The subject might be considered in detail under the following divisions; Fresh air, its composition and properties; the impurities generated in mines, and their probable amount; the proportion in which these impurities may be allowed to exist in any space occupied by human beings; the quantity of fresh air that must be supplied to mines, and the best method of introducing it artificially, when natural or unaided ventilation cannot be relied upon.

Pure air consists, approximately, of 23 per cent. of oxygen and 77 per cent. nitrogen, weight for weight, or 21 per cent. of oxygen and 79 per cent. of nitrogen, comparative volumes. In addition, the air always contains carbonic acid; the quantity is very small, for Angus Smith states that on the hills of Scotland the proportion was found to be 3·3 in 10,000 parts; in the open parts of London 3 in 10,000, and in London streets 3·8 in 10,000. Fresh air may be practically considered to contain 3½ parts of carbonic acid in 10,000 parts, and to be at an average temperature of 60° F., at which temperature the weight of a cubic foot of air is 0·0765 lb. The specific gravity of air being 1, that of oxygen is 1·1, nitrogen 0·97, carbonic acid 1·52. Carbonic acid consists of 6 parts by weight of carbon and 16 parts by weight of oxygen; the volume is the same as that of oxygen; this gas is therefore $\frac{6}{16}$ heavier than oxygen. In mines it appears in much larger proportions as choke-damp. In strata containing large quantities of hydrogen proto-carbide, as fire-damp, this finds its way into the atmosphere. Although the only impurity in air is not carbonic acid, Angus Smith considers that, as a rule, the most convenient chemical test is for the presence and quantity of this gas, and that, if enough fresh air be introduced to keep the proportion of carbonic acid at a certain point, it will be sufficient to render the ventilation effective. The following table gives comparison of the proportions of carbonic acid generally present in the atmosphere;—

	Parts by Volume of Carbonic Acid in 10,000 parts of Air.
Mines, largest amount	273·0
„ average of 339 trials	78·5
Worst parts of theatres	321·0
Close buildings, average	16·0
Streets of Manchester during fog	6·8

Nasse has tabulated the results of daily observation, taken in the Gerhard Prinz Wilhelm mine, near Saarbruck, extending over a period of twelve months. The observations were made immediately in front of a series of stoppings which closed off some workings. The gas was registered as weak, if merely sufficient to catch fire in a lamp held up in the cutting, in the roof at the face of the stopping; very strong, if it was hanging under the bars of the timbering in the heading leading up to the stoppings, and entirely filling up the cutting. During the year, gas was found on twenty-six, and in the aggregate on one hundred and fifty-one days; four times the gas remained for one day

only; on the other twenty-two occasions it lasted for several days, and in one instance for a whole month. The gas was registered as weak sixteen times, and very strong only thrice, the remaining registrations being marked average. Comparing the mean yearly pressure with the barometer readings on the first days of the twenty-six periods, the average pressure during the existence of gas, and the lowest readings during each period, it is shown, respectively;—That on nine of the first days the barometer stood above, and on seventeen days below, the mean yearly pressure. That the average pressure during the separate periods was seven times higher, and nineteen times lower, than the mean yearly pressure. That even the lowest readings during these periods were twice, 0·12 in. and 0·14 in., higher than the main yearly pressure. It is thus evident that none of the methods of comparison account satisfactorily for the effluence of gas in coal mines, although the observations clearly demonstrate that a diminution in pressure favours it; in fact, in every case, gas only appeared with a falling barometer, and any important continued diminution added to the quantity. On one occasion there was an effluence of gas for two days, when a fall of only 0·11 in. was registered, but in all other cases there had been either immediately before, or commencing simultaneously, a fall of more than one-fifth of an inch; moreover, with few exceptions, every fall of the mercury to such extent was coincident with the appearance of gas. These exceptions were within a very short period, and it is suggested that they may have been due to some meteorological influence at that season. The conclusion may therefore be drawn, that wherever there is a continuous diminution of pressure to a certain extent, gas may be expected; and, as there is a greater margin for such decrease the higher the mercury stands, it is evident that, practically, a high barometer is more dangerous than a low one.

It results from a further analysis of these observations, that the gas disappeared, on fifteen occasions out of twenty-two, only when the pressure on the last day was higher than on the first; and that, of the seven exceptions, those which showed the greatest difference in relative pressures, 0·14 in., 0·26 in., and 0·30 in., were after exceptional periods of duration of fourteen, ten, and thirty-one days respectively. In these cases it was probable that the extra diffusion of gas caused by the long-continued low pressure had weakened the volume of gas behind the stoppings.

The actual power required to effect the movement of the air at an efficient speed, so as to reduce by artificial ventilation the carbonic acid to a certain proportion, needs consideration, as well as the best means of applying that power. The friction of air varies as the square of the velocity multiplied by the pressure against the sides of the passage. This pressure being uniform, its total amount depends upon the total surface, that is, the length multiplied by the perimeter, of the cross section. The force required to propel air through any passage is therefore equal to the square of the velocity into the total surface, multiplied by the coefficient of friction. It is more convenient to state the force in pounds a square inch or foot, or as so many inches of water pressure; the preceding result should therefore be divided by the area of the cross section. According to G. J. Morrison, the best formula for practical purposes of ventilation appears to be;—

$$H = \frac{K V^2 P L}{A},$$

where H is the pressure in feet of air of same density as the flowing air; L, the length of pipe or passage in feet; P, perimeter of cross section in feet; A, area of pipe or passage in square feet; V, velocity in thousands of feet a minute; K, coefficient of friction = 0·03. This formula has the advantage of being perfectly general, and may be used for any fluid; H will always be the head stated in feet of the flowing fluid. The pressure of 1 ft. of air at 60° F. is 0·0765 lb. a square foot. The pressure of 1 in. of water is 5·2 lb. a square foot. Therefore, if it be desired to reduce any result in feet of air to its equivalent in inches of water, the process is simply to divide by $\frac{0 \cdot 0765}{5 \cdot 2} = 68$. For circular passages, taking D for the diameter, the formula becomes

$$H = K V^2 \times \frac{4 L}{D}.$$

These formulæ are applicable only to passages whose diameter is small in proportion to their length. For short passages the length should be increased by about fifty diameters of the passage. The formula for circular passages then becomes

$$H = K V^2 \times \frac{4 (L + 50 D)}{D},$$

and that for irregular shaped passages

$$H = K V^2 \times \frac{P L + 200 A}{A}.$$

The value 0·03 is reduced from a formula given by Hawksley for the ventilation of coal mines. Atkinson adopts the same formula, but gives a constant 0·26881, or nearly ten times that of most authorities. Atkinson also gives a table of coefficients depending on the material of which the passage is composed, from which the following are selected as related to this subject more directly;—

Material.	Coefficient.
Galleries of coal mines	0·254
Sheet iron, clean	0·067 to 0·105
Cast iron, old and tarred	0·048
Sheet iron, rusty	0·027
Tinned iron	0·025

Hawksley considers that these discrepancies arose from badly conducted experiments, but other authorities assign various reasons for the differences, and experiments on the Lime Street tunnel appear to confirm the constant 0·03 as correct.

The simplest plan of ventilating underground passages, which at one time was the only system adopted, and is still used in many collieries, is by the furnace. It is, however, only in the case of very great depths that this system can compete for economy with mechanical methods, and even then there are several disadvantages. The useful effect rarely exceeds 5 per cent. of the actual energy given out by the coals.

Although the subject will be found to be described in detail under its proper heading, it will be advisable to briefly review the principal constructions of mechanical ventilators. One of the first was introduced by Struvé, of Swansea. It consists of a piston, somewhat resembling a gasometer, working in a brick chamber, in an annular space filled with water. The air is admitted by and expelled through flap valves. It is well suited for extracting large quantities of air from collieries at pressures of 5 or 6 in. of water; but the large amount of clearance renders it unsuitable where the pressure is sufficient to cause a practical difference in the density of the air. The effective duty is stated to vary from 40 per cent. of the gross boiler power. There is a pair of ventilators of this description at Cwm Avon, South Wales, with pistons 18 ft. diameter and 7 ft. stroke, working 8 strokes a minute. This machine exhausts from 40,000 to 56,000 cub. ft. of air a minute, with a water gauge of 3 in. A slightly smaller ventilator at Risca Colliery exhausts 43,800 cub. ft. a minute, with a water gauge of 2·3 in.

Exhausters on a somewhat similar principle have been erected at the St. Gothard Tunnel works. These are cylinders hung one at each end of a rocking beam, which alternately dip into annular tanks of water. The space to be ventilated is connected with these air-cylinders by pipes with inlet valves, and the tops of the air-cylinders are furnished with outlet valves. Each time the cylinder rises it fills with air from the pit or tunnel, which in falling it expels through the valves on the top. These exhausters are therefore single-action pumps, while Struvé's are double-action. They are intended to work with a water gauge of 6 in., and their general design renders them suitable for much higher water gauges than Struvé's.

Lemielle's ventilator consists of a vertical drum, with movable leaves or vanes, placed eccentrically in a casing, so that the leaves lie close against the drum on one side of the casing, but expand as they pass the other, and thus sweep out a certain amount of air at each revolution. There is a ventilator of this description at Page Bank Colliery, Durham, 23 ft. in diameter and 32 ft. high. It usually works up to about 60,000 cub. ft. a minute, with a 2·6-in. water gauge, but occasionally to 97,000 cubic ft. a minute, with a 6·6-in. water gauge. The useful effect is 36 per cent. of the gross boiler power.

In some collieries the steam jet has been tried with success, as at Lower Moor Colliery, Oldham. The apparatus consists of seventy-two vertical pipes 5 ft. long and 7 in. in diameter, fitted to an iron frame on the top of the upcast shaft; into each is inserted a steam pipe having a nozzle $\frac{3}{16}$ in. in diameter, supplied with steam at 38 lb. pressure. This rough apparatus exhausts 16,000 cub. ft. a minute. Relative to this subject, in the working of pneumatic tubes between telegraphic offices in London, the steam jet has been tested against a first-rate steam engine; at 40 lb. pressure the engine does most work, but at 70 lb. pressure, the steam jet is superior. The nozzle, in this instance, is carefully constructed, and the vacuum produced is equal to 23 in. of mercury; but there does not appear to be any instance where, with a water gauge of a few inches, such good results have been obtained by a steam jet as by other means. The jet is not probably suited for exhausting large quantities of air at low pressures.

The best means of ventilation seems to be the fan. It is used in collieries and mines throughout the world, and is the only machine that has ever been applied to tunnel ventilation, which has great resemblance to mine ventilation.

The fan erected at Lime Street Tunnel is 29 ft. 4 in. in diameter, 7 ft. 6 in. wide, and runs at forty-five revolutions a minute; it is by no means of the most approved construction, but the circumstances of the case are peculiar; at times the tunnel ventilates itself through the fan, which is constructed to allow of this, the heat of the boiler fires assisting the natural ventilation. When the fan is at work the vacuum in the tunnel near the bottom of the shaft is only equal to 0·14 in. of water, but near the fan it is equal to 0·54 in. When the air leaves the fan, the pressure is equivalent to 0·19 in. of water above atmospheric pressure, this being the pressure required to drive the air through the chimney into the open air. The fan, therefore, seems to exhaust 431,000 cub. ft. a minute against a pressure of $0·54 + 0·19 = 0·73$ in. of water, which represents 50 horse-power. The actual indicated horse-power of the engine is 134. When running at forty-four revolutions, but doing no work, the indicated horse-power expended in the friction of the engine and machinery is 34. The effective duty of the fan is therefore only 37 per cent. of the gross power, or 50 per cent. of the net power. The effective duty of many other fans is, however, much higher.

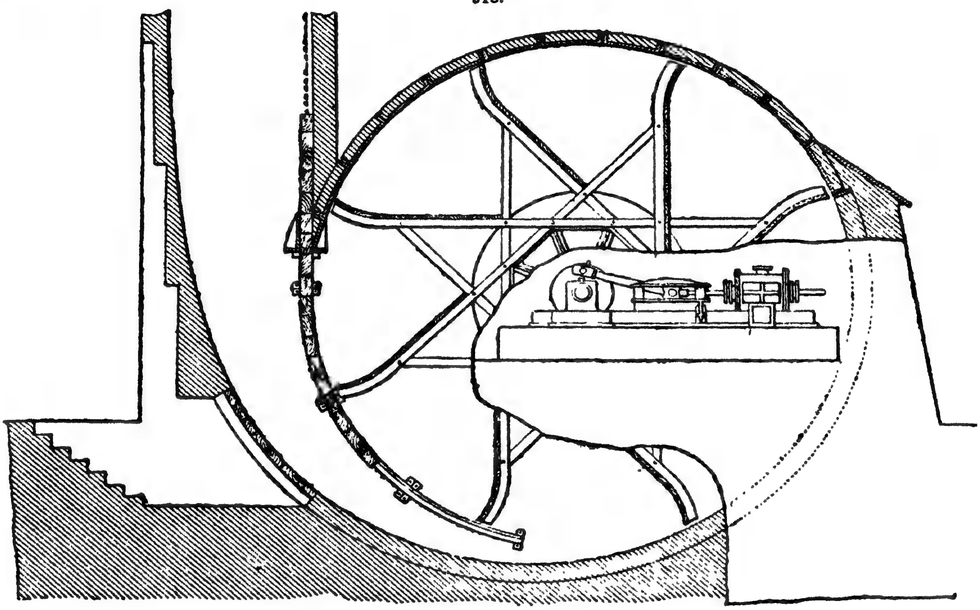
The pneumatic despatch tube at the General Post Office is worked by a fan in Holborn, 3080 yards from Euston. This fan is 32 ft. in diameter, and is driven at the rate of 160 revolutions a minute. The tube is tunnel shaped, 4 ft. wide and 4 ft. 6 in. high. The usual speed of the carriage is about 15 miles an hour. As the tube has an area of 16·3 sq. ft., the discharge is 20,000 cub. ft. of air a minute. The fan is arranged to work either for exhausting or compressing the air. At this speed the water gauge is about 10 in., and shows a useful power of 32 horses.

The Metropolitan Railway Company have lately made use of this tube for the purpose of ventilating their tunnel. The tube crosses the tunnel between Gower Street and Portland Road; and valves have have been arranged so that, on each journey of the carriage from Euston to Holborn, as soon as the carriage passes the Metropolitan tunnel, the valves open, and the air is drawn from the Metropolitan Railway instead of Euston. But the tube can only be used when the fan is exhausting, and when the carriage is between the Metropolitan Railway and Holborn; that is, about once an hour for five or six minutes.

Numerous fans have been introduced. One called the Guibal fan seems to give satisfaction. The effective duty of some of them has been stated to be 83 per cent. of the actual power put into the fan shaft; but generally it is not so high. In these fans the casing is concentric with the fan, and quite close to it, with only one opening, the size of which is regulated by a shutter. The chimney is funnel-shaped, to allow the velocity of air to be reduced before entering the atmosphere. The fact that so much of the circumference of the fan is useless for discharge would lead to the supposition that the quantity of air must be less than that discharged from other fans of equal size. It seems, however, that the useful effect of these fans is high, and that for any given discharge and water gauge the Guibal fan will work with less coal than many others, and with as little as any.

Fig. 918 is of an improved form of Guibal's fan made by Oliver and Co., of Chesterfield, which is very effective.

918.



There is a fan of this description working at Thirslington Colliery. It is 36 ft. in diameter and 12 ft. wide, and at 80 revolutions it will discharge 80,000 cub. ft. a minute, under a water gauge of 6·2 in. A somewhat smaller fan, at Gethin Colliery, discharges 153,600 cub. ft. a minute, under a water gauge of 2·6 in. It is stated by Wilkinson that he obtained 63,000 cub. ft. of air a minute from a Guibal fan, with a similar amount of steam required for 40,000 cub. ft. a minute with Struvé's ventilator.

On their first introduction fans were supposed to be applicable only to low water-gauges; but it has been found that they will work economically up to high gauges for ventilating purposes. There are some at Grand Busson, near Mons, in Belgium, 30 ft. diameter, working at 100 revolutions a minute with 7 in. water gauge.

Fans are suitable for the pressure required in all practical cases; and as they are better adapted for passing large quantities of air than any other ventilating apparatus they should be employed in all cases of artificial ventilation. The best fans appear to utilize more than 70 per cent. of the actual power applied to the fan shaft, or 15 or 20 per cent. less than the indicated power of the engine.

There remains to be considered how the ventilating current is conducted through the workings of a mine. In its distribution the air-current should have origin near the bottom of the downcast shaft. The workings of a mine are laid out in districts separated by barriers, the separation being made chiefly for the purposes of ventilation, each district having its own current, conveyed to it directly from the downcast shaft. Splitting the air, as the operation of breaking up the air into several currents descending the downcast shaft, is termed technically, enables each district to be thus separately ventilated. The volume of each current, or split, is of course determined by the size of the working for which it is intended, and by whether the working dips or rises, more air being required, as a rule, to ventilate a rise than a dip, for the reason that accumulation of gas is more likely to occur in a rise working. This accumulation may be due to a reduction of pressure, as well as to the lower specific weight of the gas. The ventilating currents seek the easiest way from the downcast to the upcast shaft, and this may be either the shortest or that having the largest sectional area. As the easiest way may not be that where most air is required, means have to be provided for directing the air in the desired volume into the proper channel, by contracting the air-way in those workings requiring less amount of air. The contraction is usually effected by doors, termed regulators, placed in the air-way. A wooden frame is built in the air-way, and one-half of the way boarded up; the remaining half of the way is blocked by a sliding door, which can be adjusted to give the proper opening, determined by experiment. The door is then secured in this position by a lock or otherwise. With a given sectional area the quantity of air passing in a unit

of time is dependent upon the velocity; by reason of the rapid increase of friction with increase of velocity, low velocities are more economical than high, although it has been found that a lower velocity than 2 ft. a second is insufficient to remove the gases, whilst a higher velocity than 3 ft. will force the gas through the gauze of a Davy lamp. The velocity most suited to ordinary conditions is 3 ft. a second.

In narrow work, one of the objects in driving two levels simultaneously is to obtain a good ventilation of the working places. The air from the downcast shaft will make its way up to the heading in sufficient quantities to keep the atmosphere at the face cool and pure to a certain distance from the entrance. This distance will depend upon the strength of the ventilating current and the vitiation. Generally the distance allowed will be from 30 to 40 yards. Supposing then each level to have been driven as far as the ventilating conditions will allow, an air passage will be cut through one to the other at that point. This passage is in many localities called a thirl, and the operation of driving it, thirling. When the first thirling has been completed, the direct connection between the shafts is stopped by building a wall of brick or stone in the drift connecting them. All stoppings which are situate by the side of the main ways should be well and strongly built, and further strengthened by a stowing or backing of 5 or 6 yds. of rubbish behind them.

As the air-way directly connecting the two shafts is stopped, the whole of the ventilating current descending the downcast will pass up the heading through the thirl, and down the heading to the upcast shaft. By these means the working faces of both headings will be ventilated by the full current. The air follows this course during the subsequent operations of driving, which are continued until the influence of the current has again become insufficient, say through another 40 yds. A second thirling is then made, and a stopping put into the first. The passage through the first being closed, the air will pass up to the new thirl, and again efficiently ventilate the working faces. These operations of driving and thirling are repeated throughout the length of the levels. When spoken of relatively to the ventilating current, the level which receives its air directly from the downcast shaft and conveys it up to the working places is described as the intake, and that which receives its air from the working places after pressing through the intake, and conveys it to the upcast shaft, is termed the return.

If the coal give off much gas, it will be impossible to continue the driving of the level throughout a distance of 40 yds. under the influence only of a ventilating current passing through the thirl; and it becomes necessary not only to bring the current up to the working faces at intervals, but to compel it to pass constantly in close proximity to those points. As it is undesirable to thirl at very frequent intervals in order to meet this requirement, the brattice is resorted to, and is similar to that used in the shaft during the process of sinking, but, being of a more temporary character, it may be more lightly constructed. The use of the brattice is to divide the level longitudinally into two portions, and to accomplish this purpose it is erected vertically. The material is chiefly wood; but in numerous cases prepared canvas, called brattice cloth, is substituted for the boarding or cleading of the wooden brattice. To ensure a strong current of air, the joints of the brattice must be made fairly air-tight. As the heading advances, the brattice is continued forward until the point for the next thirling is reached, when it is removed, and again applied to the next length. If the seam of coal is gassy throughout, the bratticing will have to be repeated from thirling to thirling, but sometimes the seam is foul at certain points only, in which case the brattice may be required only when passing these points.

Stoppings, employed to prevent the air passing by ways in which it is not required, are of permanent construction, usually of bricks laid dry, and backed up with rubbish, or of stowage closely packed. If the way is to be a travelling road, doors must be used. These are usually made of oak, the joints being rendered air tight by tongueing, and the framing inclined so that the door will close by its own weight. The door should be hung so as to open in the direction in which the loaded tubs are moving. In situations where the doors have great influence upon the direction of the current, double or even treble doors are employed, and auxiliary doors are sometimes fitted, so as to be readily closed in the event of an explosion jamming open the ordinary working doors. These safety doors are usually made to turn about a horizontal axis fixed in the roof in which they are recessed, and are then, in an explosion, out of the direct action of the blast.

When the outgoing has to be conducted across the course of an ingoing current, the plane of the former must be depressed below that of the latter. In practice it is the rule to carry the return current over the intake, by forming in the roof, above a turned arch, a passage for the return current, or by means of a stone drift in the roof rock. It is sometimes necessary to conduct the air currents through abandoned portions of the mine, the passages being built with strong pack walls. The practice is open to the objection that in consequence of surrounding earth pressure the airways gradually contract. From the fact that air expands under the effect of heat, and that the return air is always at a higher temperature than the intake, it would appear desirable that the return ways should be somewhat larger than the intake shafts. As at any time in a fiery mine gas may escape to the atmosphere of the workings, it is necessary that the air should be conveyed to the working places as directly as possible; therefore air should never be brought through broken workings and goaf, although it may, for purposes of economy, be returned through them. In conveying air through broken works on the post and stall system, the whole current, instead of being directed down one bord and up the next, is split up by stoppings placed in the headways of every second or third bord, so that the air may be distributed amongst two or three bords; this system, termed coursing the air, diminishes the resistance from friction by increasing the total sectional area of the ways.

There are many other matters connected with the winning and working of coal mines which have not been referred to here, such as the methods and appliances for lighting, arrangements for transmitting signals, modes of dealing with explosive gases, methods of procedure in serious accidents and the like, which could not be adequately treated in the space at disposal for this article, and therefore have been omitted as of minor importance to the general engineer.

Books on Coal Mining :—'A Practical Treatise on Coal Mining,' by G. G. André, F.G.S., 2 vols., 4to, London, 1876. 'A Descriptive Treatise on Mining Machinery, Tools, and other Appliances used in Mining,' by G. G. André, F.G.S., 2 vols., 4to, London, 1878. 'A Treatise on Mining,' by Callon, translated by C. Le Neve Foster, vol. i., London, 1877. 'Roy on Coal Mining,' New York, 1878.

COKE OVENS.

The nature and quality of the coke employed has so great an influence upon the manufacture of iron, that its production forms one of the chief industries in connection with the iron trade. The qualities required to form good coke are purity, solidity, and uniformity. Uniformity will depend mainly on the dimensions of the ovens employed; in the bee-hive form of oven the diameter should not exceed 11 ft., nor the height be more than 8 ft. 6 in., for it is essential that the dome should be low, as the process of burning takes place downwards. The solidity of the coke will depend upon the previous crushing of the coal to a uniform size, and upon the height of the charge in the ovens; it being found that the smaller the coal has been crushed the more solid will be the resulting coke. As an example of the advantage arising from crushing the coal previous to coking we quote the following. Owing to some peculiar condition of the coals at an English colliery, it was found impossible to make a coke of sufficient density, although nothing was traceable in the analysis, but by the application of a disintegrator such an improvement was effected that the coke was rendered thoroughly marketable. No change could be detected in the analysis, the chemical composition being such as to make it impossible to trace any cause for the previous imperfection. Purity will depend mainly upon that of the coals employed; and is obtained, in the case of slack or other coal containing large quantities of foreign matter, by careful washing, as described in the article Coal Washing. The following analysis of coke made from washed and from unwashed coal will show the advantage obtained by thoroughly washing the coal before coking. In each case the coal was coked for forty-eight hours, and in similar ovens.

Analysis of Coke from Washed and Unwashed Coals.

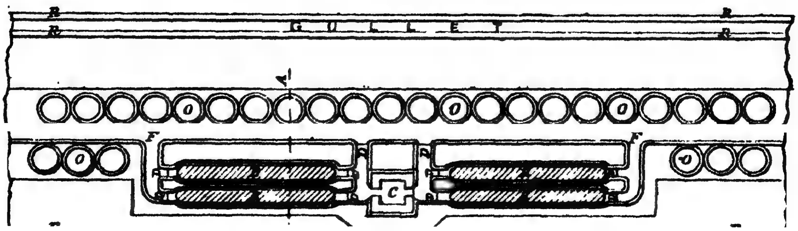
Sample of Coke.	Percentage of				
	Fixed Carbon.	Volatile Matter.	Ash.	Sulphur.	Water.
No. 1. Small coal, as delivered from pit	71·55	3·53	23·21	1·15	0·56
No. 2. Small coal, moderately washed	84·37	2·88	11·48	0·71	0·56
No. 3. Small coal, thoroughly washed	91·82	0·04	7·45	0·55	0·14

For obtaining as large a quantity of coke as is possible from a given quantity of coal, various forms and systems of ovens are employed; but though for some kinds of coal special ovens and systems of working may be of service, it is generally found that the old round form of oven or bee-hive is the best; as from the simplicity of its construction, it is the cheaper in first cost and also for repairs. With this form of oven the tendency to wear out by the contraction and expansion arising from frequent cooling and reheating is also considerably less than with many other forms; while at the same time the concentration of the heat will be greater and there will be a smaller percentage of side coke produced.

The last consideration is economy of production; for though we may obtain a large yield of coke of an excellent quality, yet if the conditions are such as to necessitate a considerable labour in charging the ovens and withdrawing the coke, so much expense may be incurred as to render its manufacture unprofitable. The ovens should be so arranged as to allow of the charge being introduced from above direct from the coal trams; this not only reduces the amount of manual labour, but as the charging is performed in a much shorter time, cools the ovens less, and consequently the lighting up of the new charge is sooner accomplished than under the system of charging through the doors.

The coke ovens at the Brownery Colliery are shown in Figs. 919 to 921; Fig. 919 is a plan; Fig. 921 a section on the line A; and Fig. 920 a front view of one of the ovens. These are con-

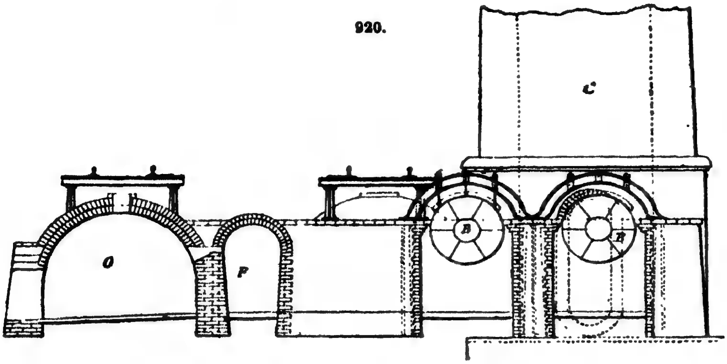
919.



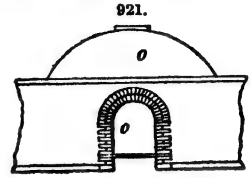
structed on the ordinary bee-hive type, with certain modifications in the construction and arrangement of the flues, for the purpose of utilizing the waste gases for the heating of the boilers B. The ovens O are 11 ft. in diameter and 8 ft. high at the crown, the floor having a fall of about

9 in. from back to front; they are built in double rows, back to back as usual, but the flues F between them are much larger, averaging 6 ft. 6 in. in height by 3 ft. 6 in. in width. To each chimney C, of 120 ft. in height, about 100 ovens are connected, an equal number on each side, and the flues and boilers B, four in number, are so arranged that the heat can be carried past when cleaning or repairs are requisite, the small connecting flues D being built as compact and tight as possible, and thus freedom from smoke is obtained, owing to the air-tight character of the flues, the small amount of air present in excess not cooling the gases below a point at which the hydrocarbons escape imperfectly burnt. This has been tested by admitting a large quantity of air, when smoke was immediately evident. The saving which has been effected at the above colliery by this arrangement of ovens and boilers is about 300 tons of coal a week, which was the amount previously consumed for the boilers, while since these improvements were introduced not any coal has been used either for the pumping or winding; the depth of the pit being 100 fathoms. The yield of coke from the ovens averages about 60 per cent. of the coal, of the following approximate composition:—

920.



921.



Carbon	96·16 per cent.
Ash	3·84 ,,

The analysis of the coal used being as follows:—

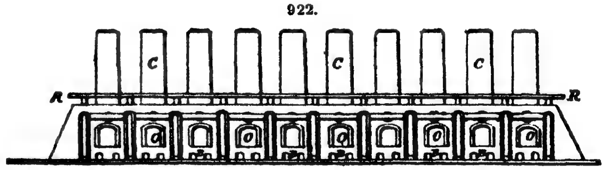
Oxygen	6·6 per cent.	Nitrogen	1·0 per cent.
Carbon	85·0	Sulphur	0·6 ,,
Hydrogen	4·5	Ash	2·3 ,,

The total theoretical heat which is developed in the process of coking is thus expended;—

Heat utilized by boilers	14·0 per cent.
,, escaping in chimney	15·0 ,,
,, lost in radiation from ovens and flues	71·0 ,,

From this it will be seen that even with these improved arrangements only a very small percentage of the total heat which is generated in the ovens is utilized; but even under such circumstances it is estimated that if the system were adopted throughout the whole of the South Durham District, where in colliery boilers not more than 6 lb. of water is on an average evaporated to the 1 lb. of coal, it would effect a saving of 1,085,869 tons of coal in a year.

922.



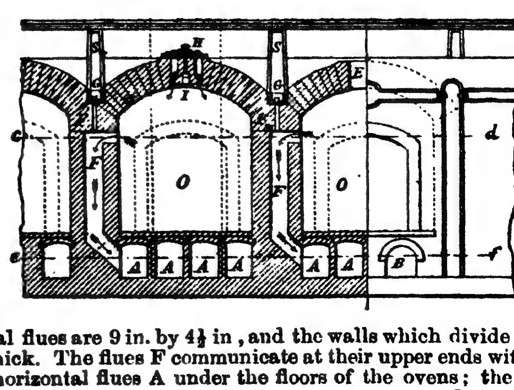
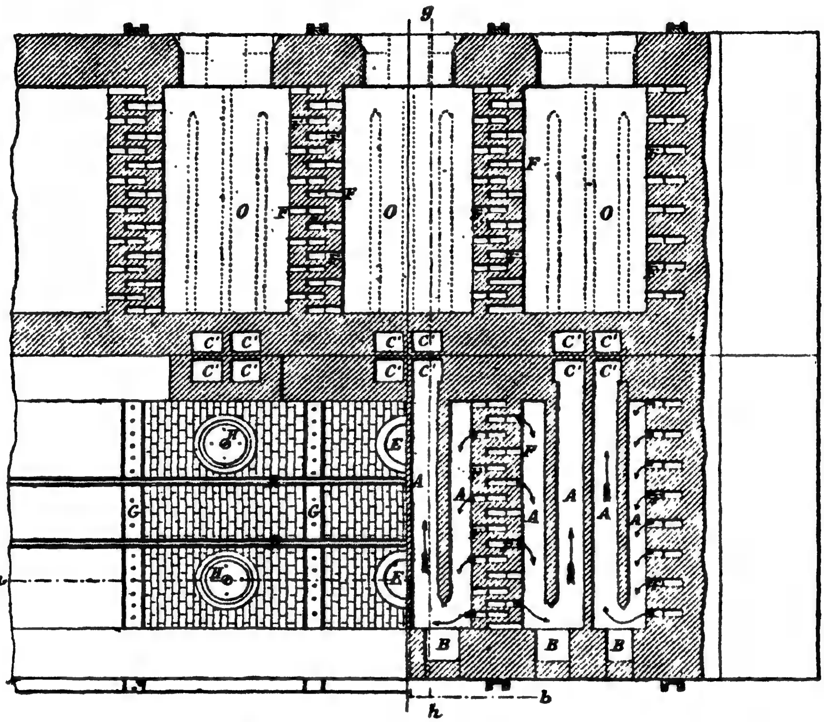


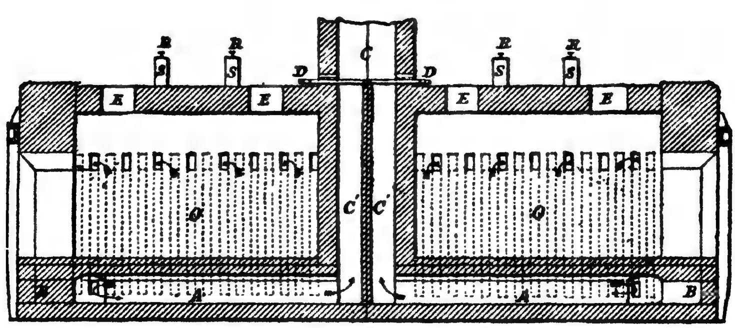
Fig. 922 is an elevation of a double row of twenty Gjer's coke ovens, as erected at Lloyd and Co.'s Ironworks; Fig. 923, an elevation partly in section on the line *a b*, Fig. 924; Fig. 924 is a plan, the bottom left-hand corner showing the top of the ovens, the right-hand bottom a section on the line *e f*, Fig. 923, and the upper part of the figure a section on the line *c d*; and Fig. 925 is a cross section on the line *g h*. These ovens O are 11 ft. 6 in. long by 6 ft. wide inside, and are 7 ft. 6 in. high at the centre. Each oven has eight vertical flues F on each side, which are placed at such a distance apart as to accommodate between them the corresponding flues of the adjoining ovens; these vertical flues are 9 in. by 4½ in., and the walls which divide them from the flues of the next oven are 4½ in. thick. The flues F communicate at their upper ends with the ovens, and at their lower ends with the horizontal flues A under the floors of the ovens; the flues

A being each 13½ in. wide by 1 ft. 6 in. high at the centre, and are so arranged that the gases have to traverse the length of the oven twice before reaching the chimney. The ovens communicate separately with the chimney C by two flues C′, about 12 in. by 15 in.; and when the ovens are arranged in a double row as in Figs. 922 to 925, each chimney serves for two ovens; the uptakes C′ being provided with a sliding damper D, Fig. 925. On the top of the division walls, between the springing of the arches forming the roofs of the ovens, are placed cast-iron trough girders G, Figs. 923 and 924, having a series of holes along the bottom so placed, that each of them is immediately

924.



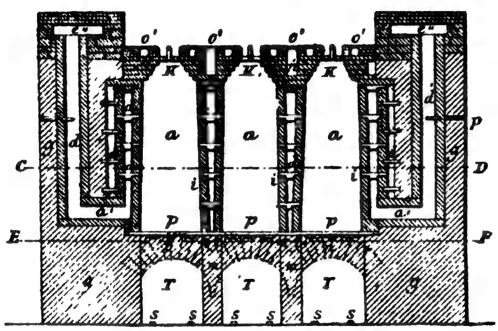
above one of the vertical flues F, and by means of a corresponding hole F′ in the brickwork, is in communication with it. These holes are generally closed by plugs, and serve either for the admission of air to the flues or for the introduction of a bar for cleaning. Arched openings B are also provided in the face walls of the oven, through which the horizontal flues A under the floors can be cleaned out. The opening in the front of each oven, through which the charge is withdrawn, is 4 ft. wide and 5 ft. high in the centre, and is furnished with the usual door. The charging is performed through



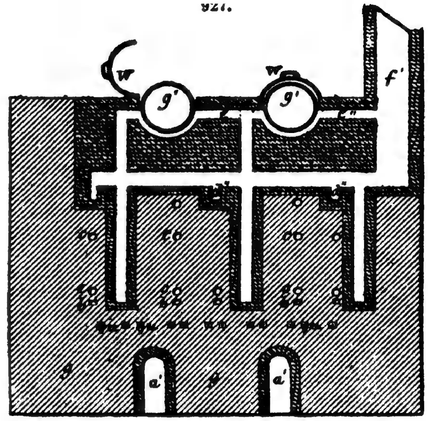
openings in the roofs, through the charging holes E, 1 ft. 6 in. in diameter, which are closed by cast-iron doors H, furnished with plugs I of fireclay to protect them from the heat of the ovens; each cover has four holes formed in it, and a revolving plate to regulate the width of the openings. Between the charging holes is a line of rails R, supported by standards S, which are fixed to the trough girders G. In working, the charge of every alternate oven is drawn when the ovens on either side of it are in full work; immediately the charge is withdrawn, the door is closed, and the oven recharged

through the openings E, the top covers H are then replaced, the holes in them being left open for the admission of air. The gases rising from the newly-charged coal, mixed with the air admitted at the top of the oven, enter the side flues, where, being highly heated by the heat communicated from the flues of the adjacent ovens, they inflame and are consumed. If the air admitted through the openings in H is not sufficient to completely consume the gas, a further quantity can be admitted into F through the holes in G, but it is found preferable to admit the whole of the supply at the top of the ovens. The heat generated in the flues is very intense, these are lined with firebricks; it is also necessary that the ovens should be built upon a foundation which will not be affected by heat. When charged with coal to a depth of 4 ft., or with from 8 to 9 tons of coal, the ovens can only be drawn twice a week, but the coke produced will then be of the best quality and of great strength and hardness; if, however, they are charged with South Durham coal to a depth of 2 ft. 6 in. or 3 ft., or with from 5 to 6 tons each, they can be drawn three times a week, and the coke, although not so fine as when a heavier charge is worked, will still be excellent. The yield of coke is stated to be from 12 to 15 per cent. greater than from the ordinary round oven.

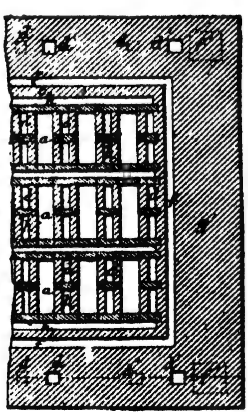
At Marquise, France, Appolt's coke ovens have been erected; Fig. 926 is a vertical section, Fig. 927 a vertical section on the line $f'\ d$, Fig. 928 a horizontal section on the line E F, Fig. 926,



927.



and Fig. 929 a section on the line C D; Fig. 930 a vertical section on i K, Fig. 926. The block of ovens consists of a wall 5 ft. 5 in. thick, and 20 ft. high, enclosing a space 17 ft. 2 in. in length by 16 ft. 9 in. in width, this space being divided by partition walls into eighteen oblong compartments or shafts a arranged in three rows of six; each compartment measures 4 ft. 1 in. by 1 ft. 6 in inside at the bottom, and 3 ft. 9 in. by 1 ft. 2 in. at a height of 11 ft.; from this level the side walls are



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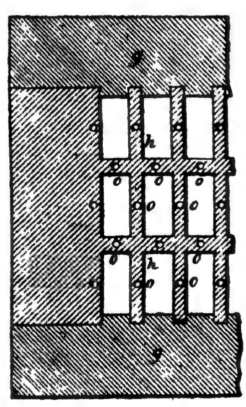
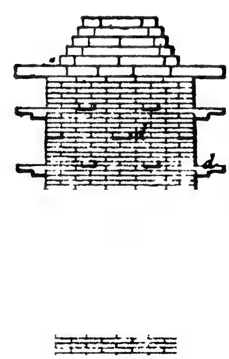




carried up perpendicularly, whilst the end walls are sloped inwards so that each compartment terminates at a height of 13 ft. 2 in. in an aperture 14 in. square. Owing to the tapering form, spaces d are left, which communicate with a by means of the openings i in the division walls; the walls of the compartments being strengthened by struts.

The compartments are built of firebrick, and the outer walls, as well as the flues and other parts exposed to the heat, are lined with the same material, and on the top of the block rails are laid. Beneath are three tunnels T separated by walls m; in the crowns are openings corresponding to the several compartments above, and closed by the cast-iron doors p, which are constructed as in

Figs. 931 to 933; these doors allow the coke to be discharged into waggons which run on the rails S, an operation much facilitated by the tapering form of the compartments. The doors *p* are strengthened with cross pieces *f s* or *r*, Figs. 931 to 933, and hinged at *q*. *o* are cast-iron pipes 3 in. in diameter, communicating with the spaces; other openings *c′* are also formed at different heights in the outer walls for admitting air; they are fitted with regulating plugs. The products of combustion are led off from *d* by the flues *d′* and *d″*, which leave at two different levels on each side of the oven, and are connected by the system of flues *e″*. *g′* are two wrought-iron cylinders, used for drying and heating the washed coals previous to coking. In the cylinders *g′* are the doors *w* by which they are charged, and there is a wheel turning them; one of the trunnions being hollow, to allow of the escape of the steam from the coal during the drying process.

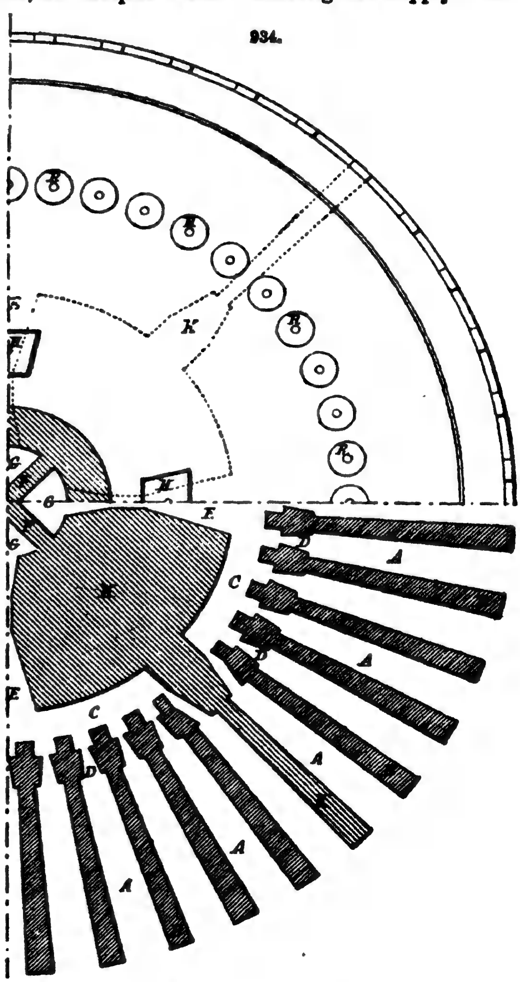
931

932.

933.

In working, the time allowed for each charge is twenty-four hours, which is stated to be sufficient for producing a good hard coke. Nine compartments are emptied every twelve hours, the alternate compartments being treated simultaneously, with the same object as in Gjer's arrangement; the gas from the fresh coal passing through the openings *i*, and being brought into contact with air, and with the flame from the other compartments, the dampers *c′* and *o* enabling the supply of air to be regulated. The main feature of this arrangement, as in that just described, is the utilization of the heat generated by the combustion of what are ordinarily waste gases. The coke is discharged into an iron waggon which is lined with thin firebricks, and on receiving the charge the waggon is hauled out and the coke quenched. The door *p* is then closed, and a scoopful of small ashes is emptied into the compartment from the top; these ashes lie upon the bottom door *p*, and prevent it and the surrounding ironwork from being injured by the heat. An iron corve, having a hopper bottom, and containing 24 cwt. of coal, is then brought over the compartment, and its contents discharged through the hopper; this operation is performed almost instantly, and the top cover K being then put in place, and luted with a little wet clay, the oven is in full work again. The yield of coke obtained from these ovens averages about 80 per cent. of the weight of coal, or about 18 tons of coke a day of twenty-four hours from each group of eighteen ovens, and this coke is of good quality.

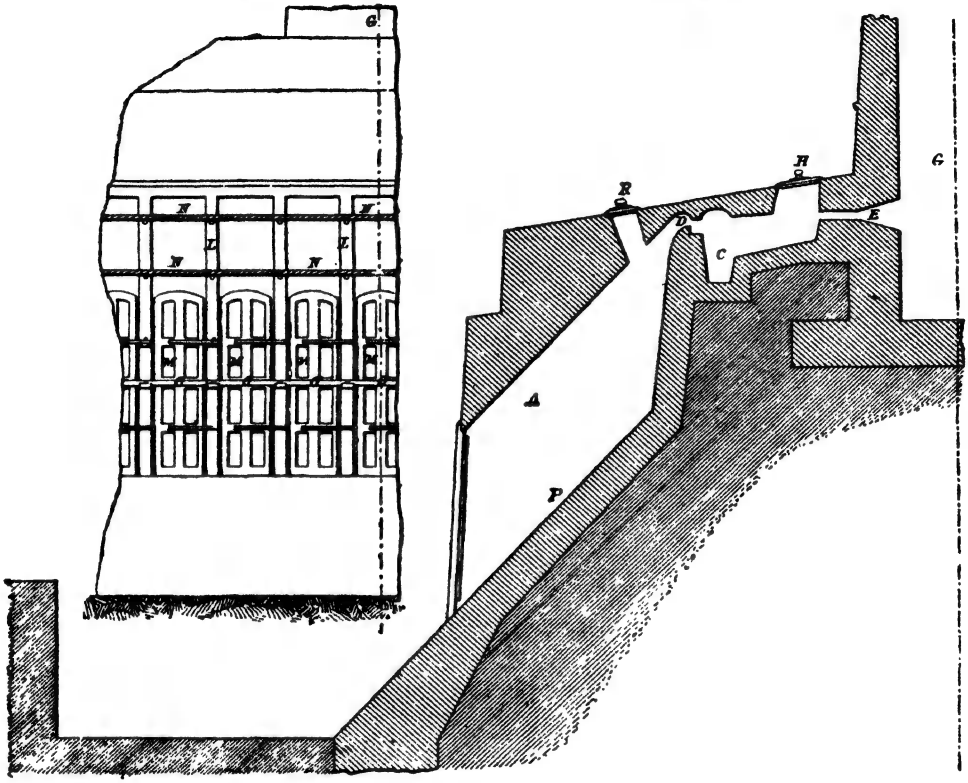
934.



Figs. 934 to 936 are of Eaton's coke ovens; Fig. 935 being a part elevation of the front of the ovens; and Fig. 936 a section through one of the cells A, connecting flues D and central chimney shaft G. Fig. 934 is a quarter plan at the top of the block of ovens, and a quarter-sectional plan showing the arrangement of the ovens A, and the flues D C E and G. Four blocks of ovens are arranged around a central chimney shaft G; the blocks being separated from each other by division walls K, and communicating with the central shaft G by a separate connecting flue E. Each portion of the block consists of a series of ovens A, whose number and dimensions are regulated by the size of the entire block. These ovens are formed by dwarf walls B, varying in height and thickness with the size of the block, and are built of firebricks, the walls being made to radiate outwards from the general flue C, which is connected by another small flue E with the main chimney shaft G, which is divided into divisions corresponding with the number of main divisions in the block, as in the plan Fig. 934, so that each section may be worked independently or the whole together. The entire block of ovens is tied and bound together by the wire ropes N. The cells A being wider at the outer end than at the end next the general flue, allows the coke a free exit when carbonized, and this is further assisted by making the bottom of each oven incline

towards the outer end at an angle of about 45°, and this inclined plane facilitates the descent of the coals. Each oven has a separate flue D leading into one of the sections of the general flue C, which receives the gas from the cells, whence it is carried off by the small flue E connected with the central shaft G. The outlets are fitted with cast-iron doors M, the panels of which are filled in with firebrick, the doors being hung to cast-iron posts L built into the walls; these doors being secured when closed by means of flat iron bars O. The general flues C are provided

935. 936.

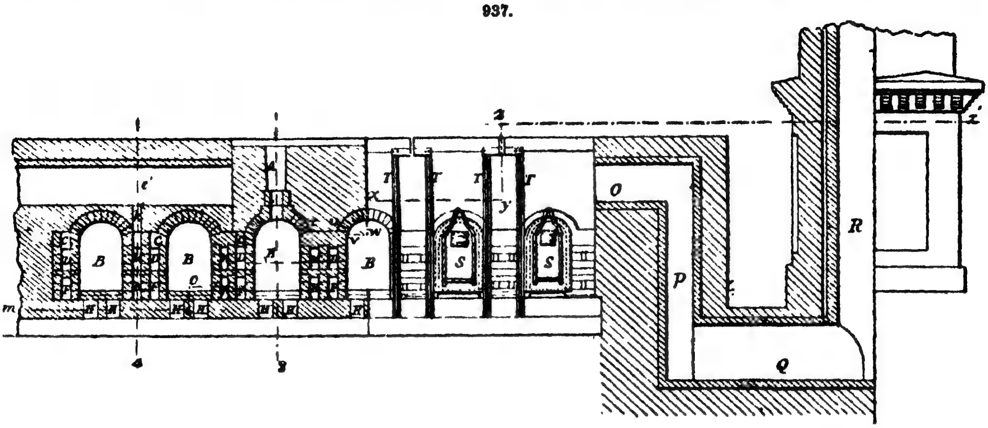


with openings for the purpose of cleaning and repairs, and these openings are closed by the cast-iron covering plates H. When the process of making the coke commences, the coals are thrown into the cells through the openings R in the tops, and so soon as carbonization commences, the gas which escapes from the coals is forced through the small opening D into the general flue C, and becomes mixed with the gas issuing from the other cells, and is finally carried off by the chimney G. Every part of the block is closed to the atmosphere, therefore there is no draught, the carbonization being produced by the concentration of the heat in the oven which is maintained by the constant supply of coals. When the gas is expelled, the coke does not waste in the oven, as the openings are closed with clay, and as the coke is removed out of the cells it is smothered with water, and by this means a very hard and dense coke is produced containing a high percentage of carbon, and possessing a brilliant and metallic appearance.

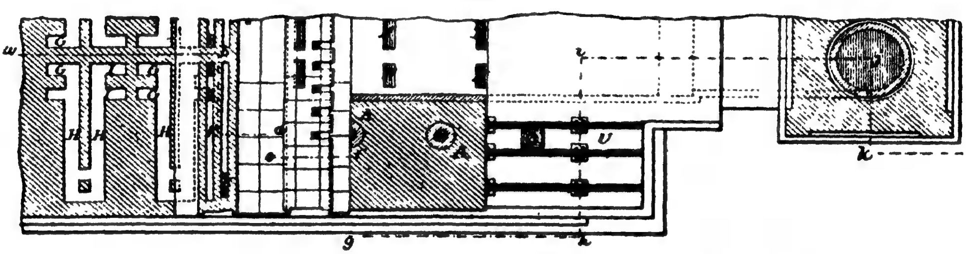
Gobiet's coke ovens, Figs. 937 to 939, are constructed on the principle of horizontal muffle furnaces; the chief object being the consumption of the smoke which is generated during the operation of coking, and so to prevent the inconvenience and annoyance arising therefrom to the neighbourhood in which the ovens are erected. Fig. 937 is a longitudinal section taken along the line *a, b, c. d, e, f, g, h, i, j, k, l*, Fig. 938, of a portion of an oven consisting of a series of coking chambers constructed and arranged on this principle; Fig. 938 is a horizontal section of the same, taken along the line *m, n, o*, to *z′*; Fig. 939, half section on 1 and 2, Fig. 937; Fig. 939* is a half section on the line 3, 4, Fig. 937. A, are openings through which the coal is introduced into the ovens B in order to be carbonized. The incandescent gases which evolve during the process of carbonization are conducted through a series of apertures C leading from each chamber into lateral flues D, running towards the respective ends of the chamber, and communicating by passages E with other lateral flues F. From these flues the gases are conducted through apertures G into flues H, arranged underneath, and following a circuitous course towards and from the ends of the chamber, which flues communicate by means of other apertures I with flues K, formed in the other wall of the chamber. The gases then escape through passages N into the main flue O, where the gases from the whole of the ovens B unite, and whence they are conducted through flues P and Q into the chimney R, which is situated at the extremity of the series of ovens. By means of this arrangement

the ovens are heated all round, whilst the gases escaping from the chimney are warm, but never in an ignited or incandescent condition, so that no smoke is emitted from the ovens during the operation of carbonizing, and all inconvenience from that source to the locality in which the ovens

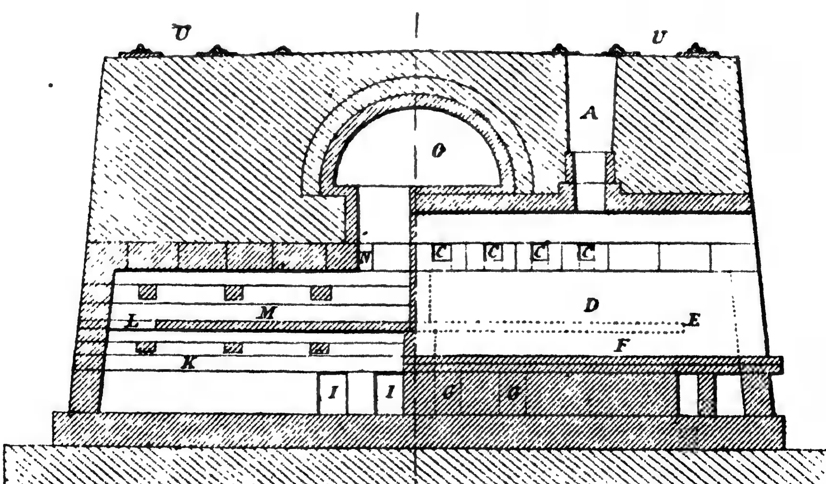
937.



938.

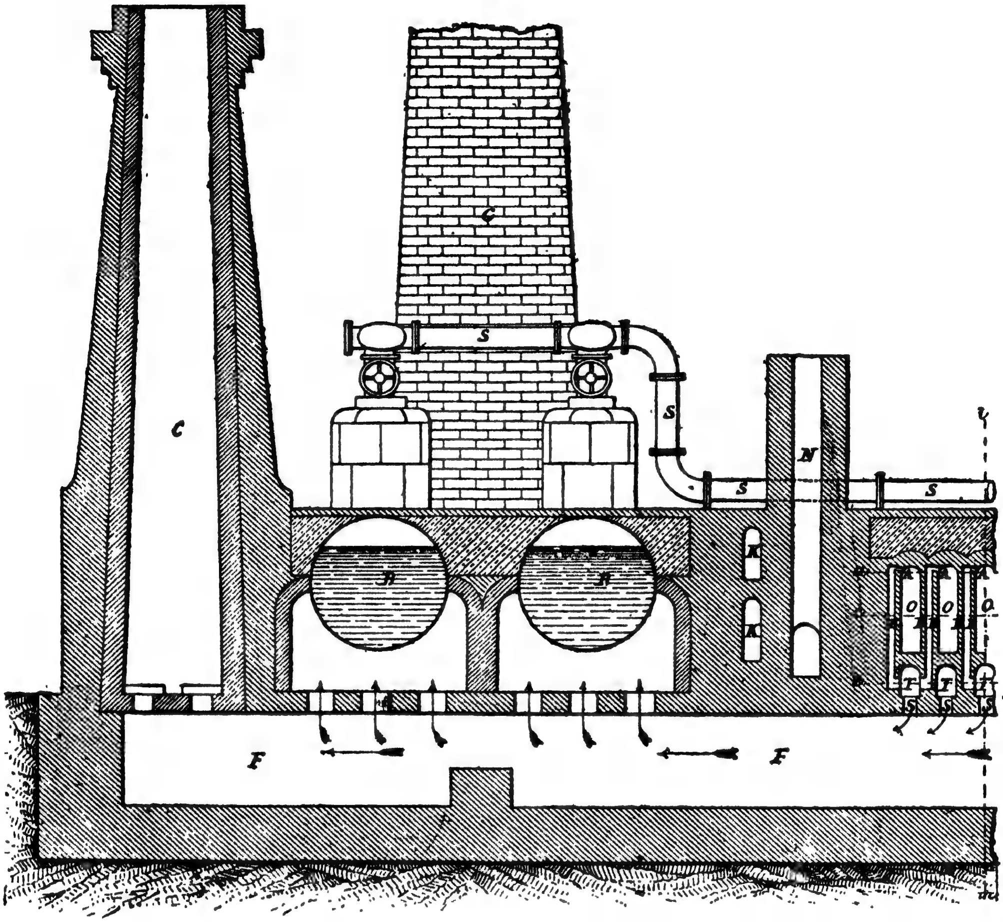


are situate is obviated. S are doors consisting of plates of iron fitted with refractory material and luted. These doors slide on iron guides, and are operated from above by means of travelling cranes running upon rails U laid longitudinally along the top of the oven. The coke is removed by means of a crane.



The Coppée coke ovens are shown in Figs. 940 to 949. A row consisting of twenty, thirty, or forty ovens, the arrangement of chimneys and boilers at each end of the block being the same; Fig. 940 is a vertical longitudinal section; Fig. 941 a vertical cross section on the line *l m*; Fig. 942 a longitudinal section showing the position of the cold air flues I, and their connection with the flues K and L, and chimney N; Fig. 943 is a plan of the top of the ovens; Fig. 944 a sectional plan on the line *a b*, and Figs. 945 to 948 are similar sections taken respectively on the lines *c d*, *e f*, *g h*, and *i k*; and

940.



941.

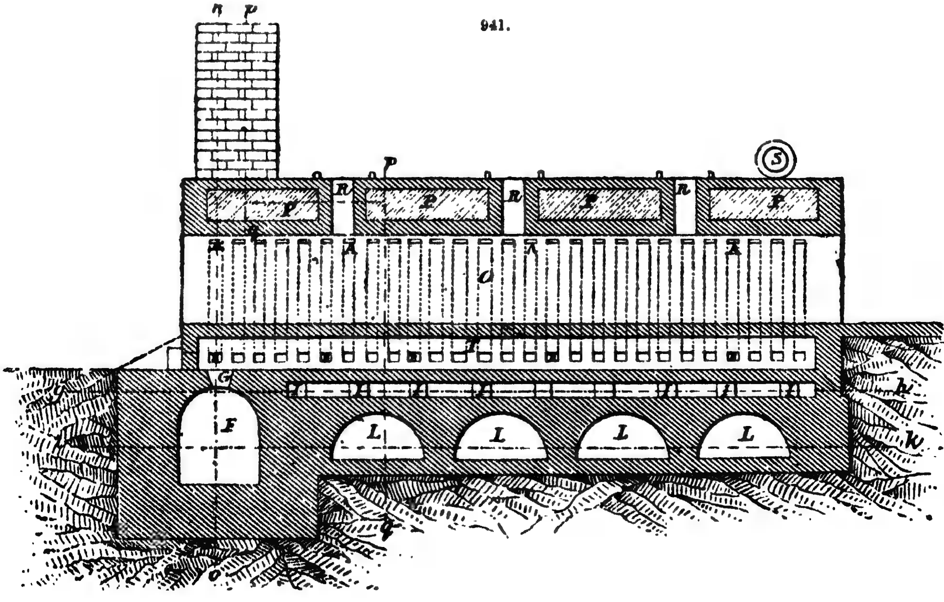
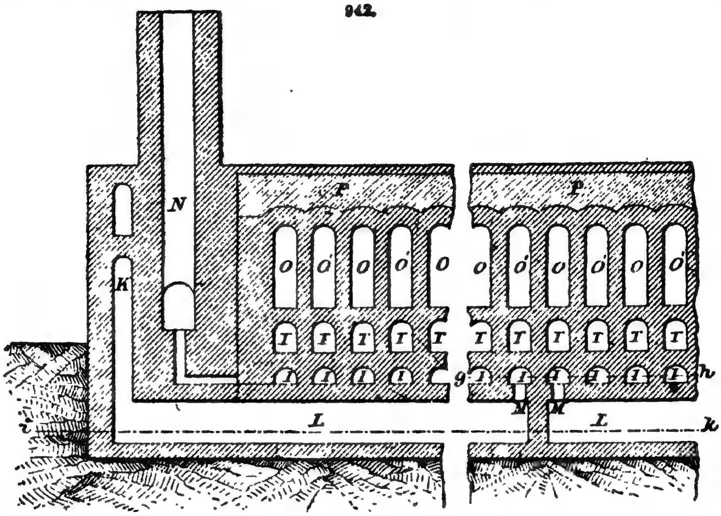
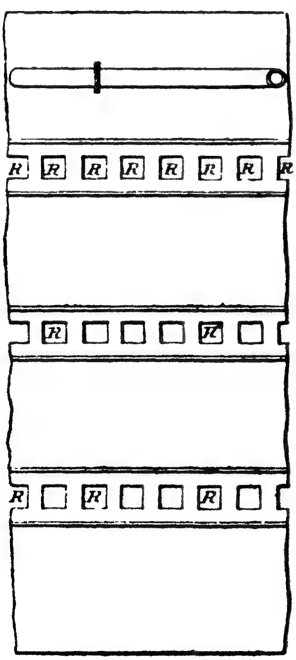


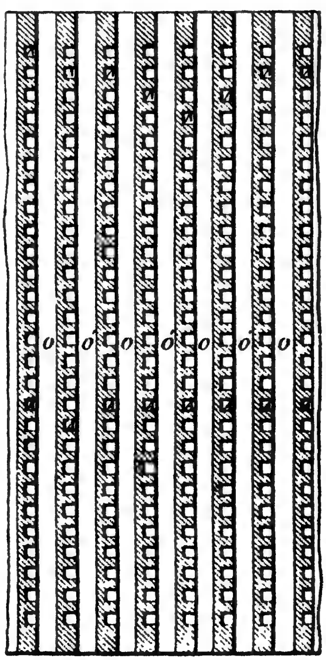
Fig. 949 is an enlarged elevation and section of two of the ovens. The coal is here coked in a comparatively thin sheet or layer between highly heated brick walls; the ovens O O′ are placed together in groups of two, any number of groups being connected to the common chimney. The characteristics of the Coppée oven are—a small width and an arrangement of channels especially suited for poor coals, it having been proved by experience that many qualities of coal which are not sufficiently bituminous to coke in ordinary ovens, may, however, be coked in the Coppée oven; the combustion of the gases evolved, by a double admission of air: the combination of all the hot gases in a common flue F, running beneath the whole range, and their utilization for heating boilers, and the employment of flues I for cooling and preserving the brickwork. The flames from O O′ pass

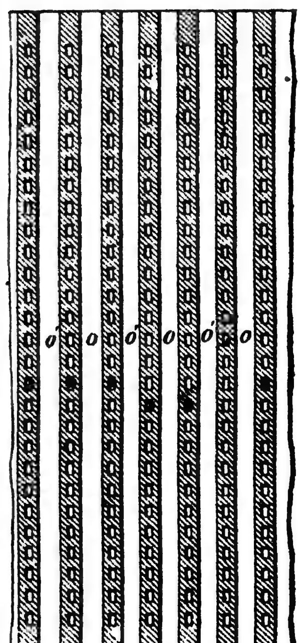
942.



943. 944. 945.



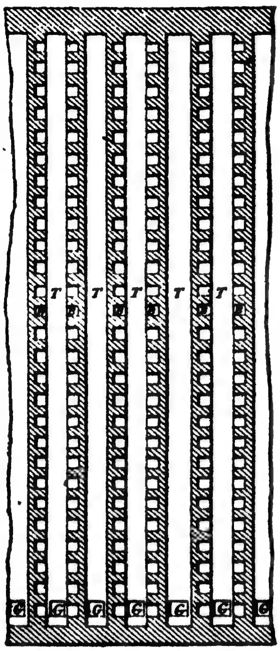




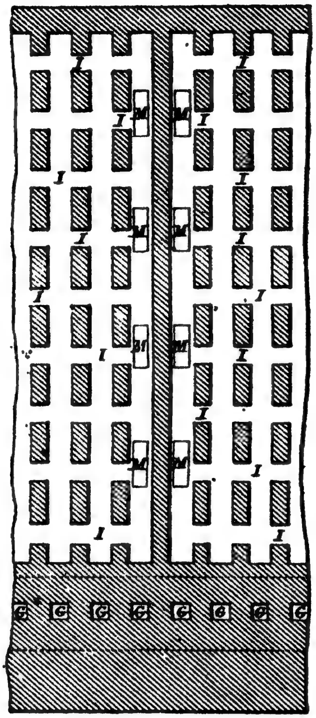
through a series of openings A, made at the springing of the arch, and circulate in channels B, then passing beneath the sole of the adjacent oven, enter by a vertical flue G into F, which first passes beneath the boilers R, and then leads to the chimney C. The gases are burnt in the channels by two sets of jets of warm air, one entering the oven at D, and the other entering the vertical flues B; the admission of the air is regulated by slide bars H and F. Galleries I under the brickwork,

are traversed by currents of cold air, which cool and preserve the structure. The air enters at K, and traverses four ordinary brick galleries L; at the point M in the centre of the block of ovens it ascends, entering the flues I in order to reach the chimneys N. To diminish the loss of heat by radiation, the tops of the ovens are covered with a bed of clay P, on which bricks are laid. The ordinary dimensions of an oven for a coking of twenty-four hours are—length, 30 ft.; width, 18 in.; height, 4 ft.; for a coking of forty-eight hours the width is 24 in., and the height 5 ft. 7 in.

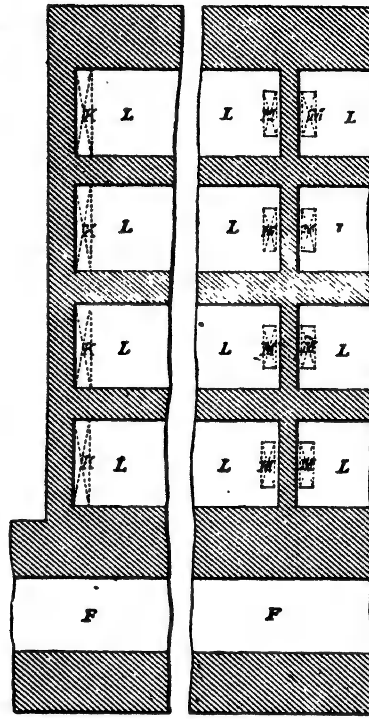
946.



947.



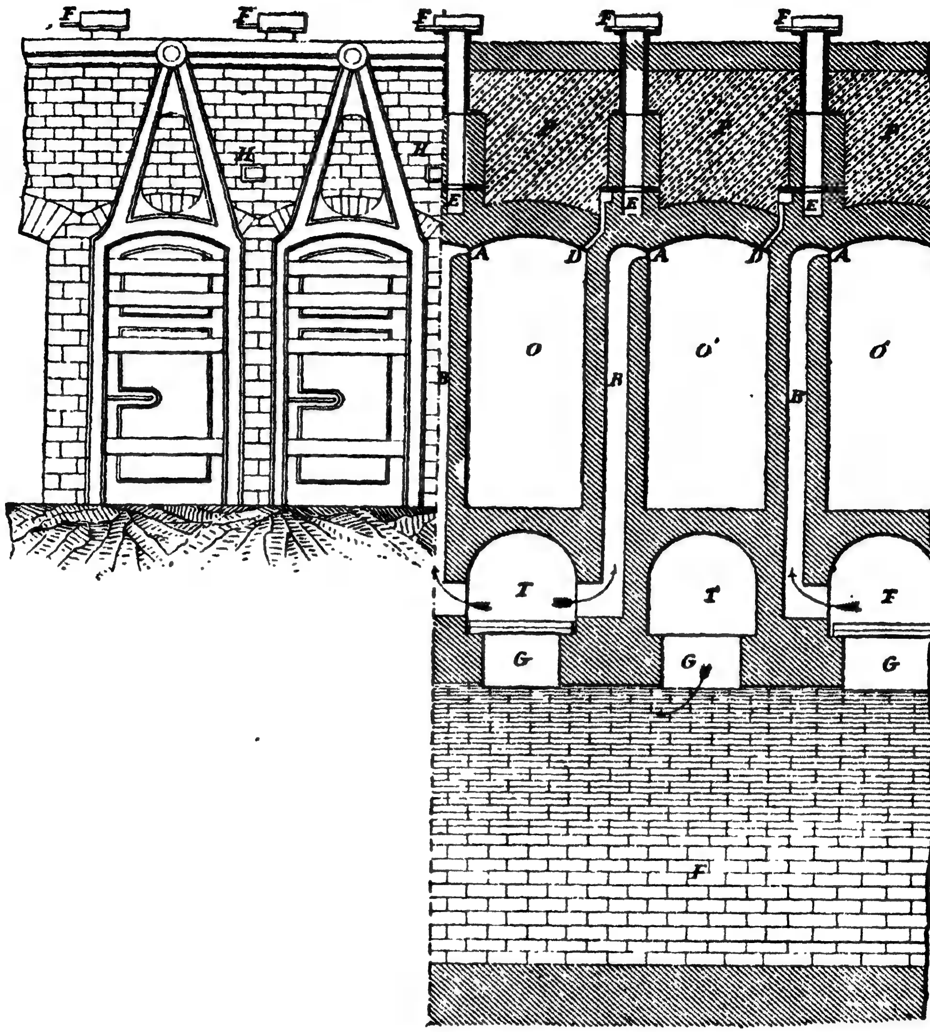
948.



The coal previous to coking is thoroughly crushed, and is introduced into the oven by the three charging holes R; the time occupied in drawing the finished charge and in refilling being only about eight minutes. The advantages possessed by this system of coke ovens are, first, rapidity of action. The coal falling into a narrow chamber which has been raised to an intense heat by the previous charge, commences burning on all sides at once, and being very fine, it is in the best condition for giving off its gases rapidly. By the arrangement of the flues, and the plan of discharging alternately, the cool gases given off by the oven just filled promptly mingle with those of the neighbouring oven, which by this time is giving off its gases at their highest temperature; the mingling of the gases raises the temperature of the one oven almost immediately to that of the other, and thus a very high and uniform temperature is maintained. The thin layer of small coal burning on all sides at once, the volatile gases are rapidly expelled, and the oven is ready to be drawn in one-third of the time required by the ordinary ovens. A second result is, that a largely increased yield is secured, being not less than 10 tons of coke for every 100 tons of coal coked. The third result is, an improved quality of coke; the coke produced by this system being remarkably hard and dense, and this hardness is probably in a great measure owing to the crushing to which the coals are subjected previous to coking. There is also a slight saving of labour by this system. A further advantage claimed for these ovens is their adaptability for the utilization of the waste gases for the production of steam; no extra expense being required to the ovens themselves for flues and the like, there is only the ordinary cost of boilers and chimneys, which can be added to a group of ovens at any time. The quantity of steam produced will vary with the quality of the coal and the system of boiler adopted; but from 2 to 4 horse-power an oven can generally be obtained. These ovens are discharged by means of a crane and a ram, which enters at one end of the oven and forces the coke out at the opposite end.

In Figs. 950 to 952 are shown the coke ovens erected in 1872 at the works of the Société de l'Espérance, at Seraing, Belgium; at which place the manufacture of coke is conducted on a very large scale, all the small coal which is raised being washed and converted into coke, 300 ovens being employed for the purpose. The ovens are built in one block of forty-two, the dimensions of each oven being—length, 31 ft. 2 in.; height, 5 ft. 9 in.; and width, 2 ft. 4½ in. Fig. 950 is a longitudinal section; Fig. 951 shows an end elevation and a cross section of three ovens; and Fig. 952 is a sectional plan on the line *a b c d*. The burning gases which are evolved from the coal pass through the openings A, situated on each side, into the flues B, thence into the main flues C, and

949.


F
F
F
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F
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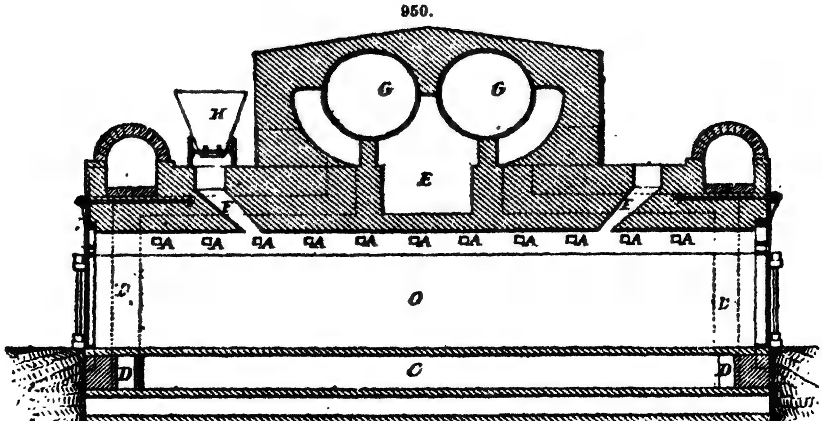
950.


G
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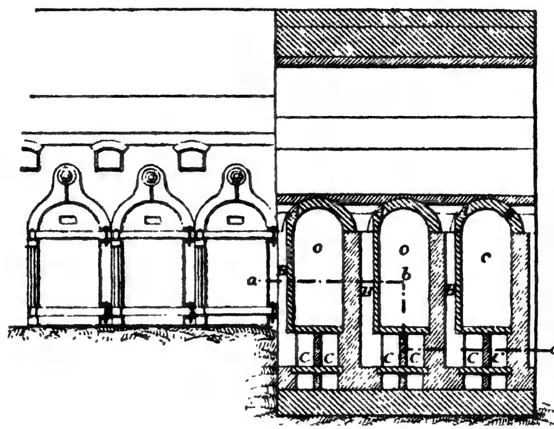
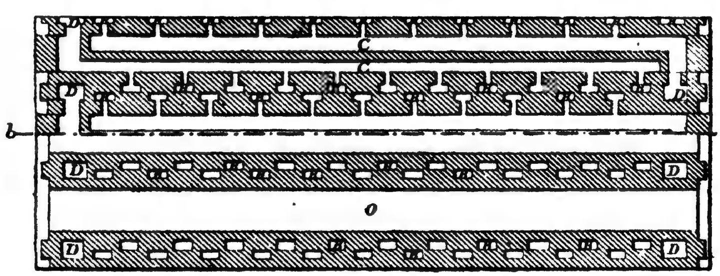
from there they pass by flues D into the chamber E which opens into the chimney. In the chamber E are set six plain cylindrical boilers, 4 ft. 11 in. in diameter, and 46 ft. in length, which are used for supplying steam to the pumping and winding engines. Suitable means are provided for shutting off the hot gases from any two boilers, so as to allow of any necessary repairs being effected. The heated gases after passing under the boilers G are discharged into a chimney 164 ft. in height, and having an internal cross sectional area of 43 sq. ft. The charge is fed into the ovens O from the waggons H, by the openings and shoots F, and consists of 7 tons 14 cwt. of small coal, yielding

951.



6 tons 4 cwt. of coke, or about 80 per cent.; and this coke is clean and hard, and free from sulphur, this latter quality being most probably due to the very careful washing which the coal receives previous to coking. The time occupied in coking is forty-eight hours, so that the daily produce of each oven is 3 tons 2 cwt., or rather more than 130 tons of coke a day of twenty-four hours for the whole block of forty-two ovens. The coke is discharged by means of a steam stoker, which traverses, on four sets of rails, the whole distance in front of the block, so as to be brought opposite the entrance to each oven as required.

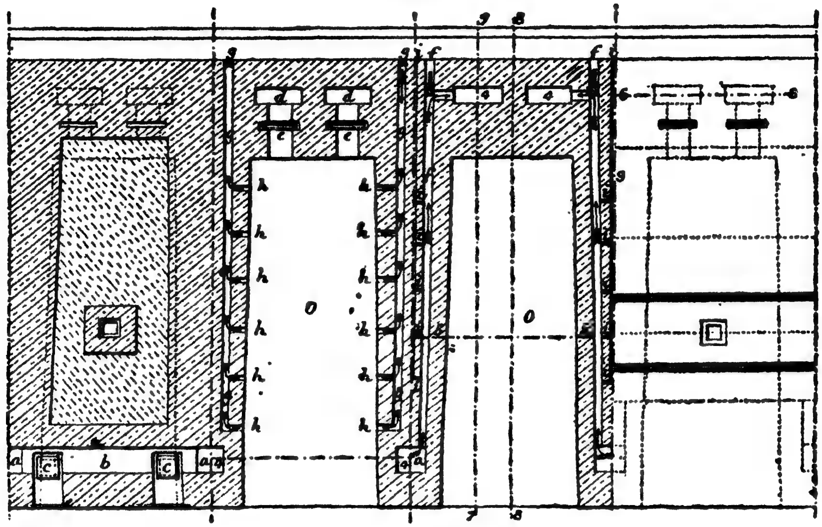
952.



Galloway's improved coking ovens are shown in Figs. 953 to 956. Each block of ovens is provided with two main common flues running the whole length of the block, and communicating by smaller flues and openings with the interior of each of the ovens. One of these flues, called the gas flue, G, is used for collecting the heated gases from those ovens which are in full operation, and to discharge it through those ovens which are empty, or which have been newly charged, so as to expedite the ignition of the charge, and thus to save time in the process of coking; the heated gases may also be distributed from the main gas flue through heating flues constructed in the partition walls between the ovens, and thus assist in maintaining a high and constant temperature throughout the whole of the block. C is the ordinary chimney flue by which the spent gases are conveyed to the chimney. The ovens, illustrated, are in the form of horizontal retorts with arched roofs; but this system is equally applicable to the bee-hive or any other form of coke oven. Fig. 953 shows four ovens, forming part of a single-row block, one of the ovens being in plan, and the others in horizontal section on the lines 1, 2, 3, Fig. 954, which is a front elevation, and vertical cross-sections on the lines 4, 5, 6, Fig. 953. Fig. 955 is a vertical longitudinal section on the line 7, Figs. 953 and 954; and Fig. 956 is a similar section on the line 8. The main chimney flue C and the main gas flue G are constructed parallel to and near each other beneath the ovens O, which they cross, running along under the entire row of ovens. The gas flue G is nearer the outer ends of the ovens, and at each part between the ovens it communicates by a vertical flue a with an upper horizontal flue b constructed across the front ends. This upper gas flue b communicates with O by two short branch flues c provided with dampers. The chimney flue C has in communication with it, at the back of each oven O, two vertical flues d, which communicate with the

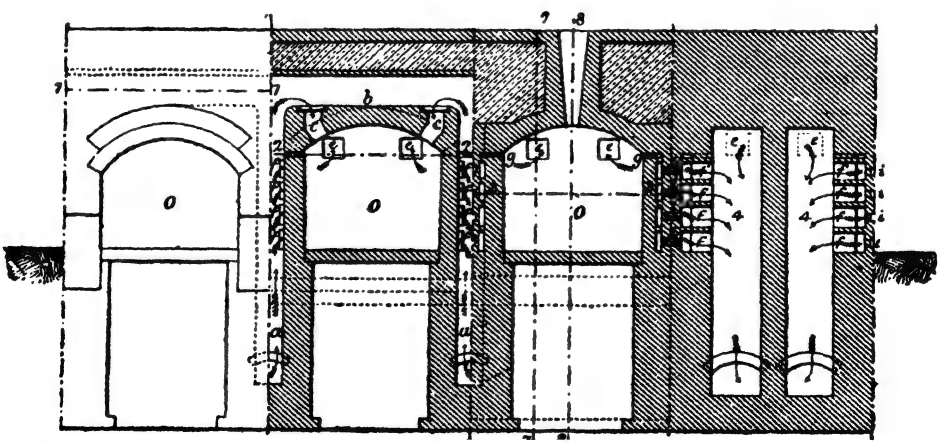
oven by short branch flues *e*, also provided with dampers. A number of small horizontal heating flues *f* are formed at each side, which connect the front gas flues *a* with the chimney flues *d* at the back, the proportion of gas passing through these flues *f* being determined by means of regulating valves. There are two sets of air-inlet passages provided, both entering from the back of the block, the one set *g* communicating with the interior of the oven O by a series of small inlets *h*, and supplying the air required for the imperfect combustion taking place in the ovens, the amount being determined by a regulating valve at the outer end of the passage. The other air-inlet passages *i* communicate with the heating flues *f* by small inlets, and supply air for the

953.



combustion of the gas in those flues. In Fig. 955, where the charge is supposed to be in an advanced state of coking, the arrows show the air entering the ovens O by the inlets *h*; and the gaseous products evolved from the charge, passing by the flues *c b a* into the main gas flue G; but in Figs. 953, 954, and 956, the arrows indicate the direction of the currents as they are when the gases from the flue G are directed through an empty or a freshly-charged oven. The change of direction in the currents is brought about by opening the dampers in *e*, which are closed when the currents are in the direction of the arrows in Fig. 955. The dampers in *c* do not require to be closed,

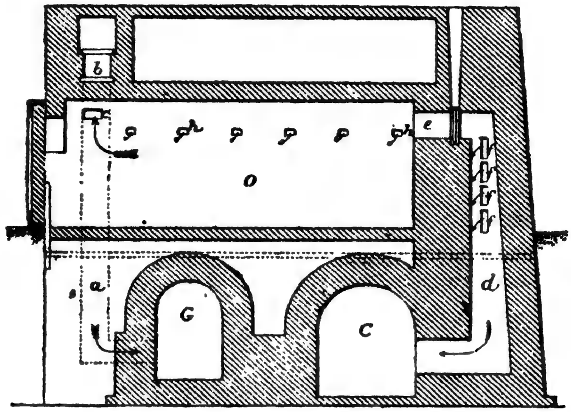
954.



except when drawing the finished charges. In working a set of these coke ovens, the several ovens are discharged and recharged alternately in regular rotation, the gases from the ovens in which the charges are in their more advanced stages being utilized in heating up in succession the emptied and freshly-charged ovens. With these arrangements the heating up is effected in very much less time than in ordinary coke ovens, and also with very much less consumption of the carbon of the coal; and where convenient or desirable the consumption of the carbon of the coal that is being coked may be still further reduced, or entirely avoided, by supplementing the gases in the main gas flue G with combustible gas formed apart from the coke ovens. When a charge

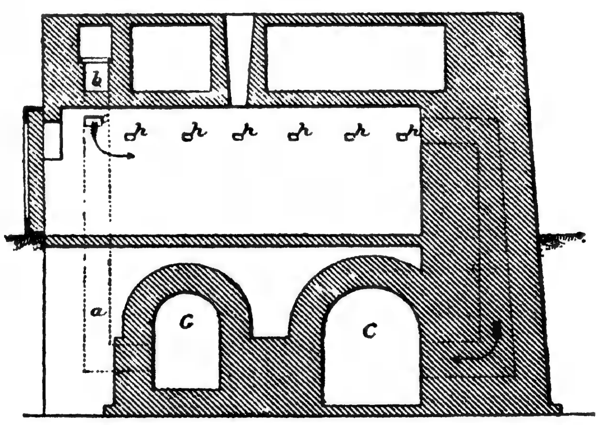
in any oven has been thoroughly ignited, and the coking process is in full operation, the dampers in, or controlling, the branch flues of that oven are set so as to cause the gaseous products from it to pass into the gas flue G, or partly into the gas flue and partly into the chimney flue C. From the gas flue G the gases are directed so as to pass through any oven that is empty and about to receive a charge, also through any freshly-charged oven, so as to expedite the ignition of the charge

955.



therein, and also through the heating flues *f* in the oven walls. The gases led in this way into empty or recently-charged ovens traverse them and pass off thence by *e* into the flue *c*, which also receives the gases that have passed through the heating flues *f*. These movements of the gases are produced by the chimney draught, or if convenient by gas-exhausting apparatus in connection with the chimney flue; the movements being regulated mainly by means of the dampers

956.



in *e*, connecting the ovens with the chimney flues. Operators soon get skilled in working these ovens, and they can then be made to coke very economically.

COPPER.

Copper, one of the most used of the commercial metals, has been produced from the earliest times by processes that are, to a certain extent, wanting in economy. The introduction of electricity, that promised much, has not met with extended practical application in the reduction of copper, metallurgically considered. As far as this agent has been applied in an engineering sense, the use will be found described under the head of Electricity. The greatest improvement in the obtaining of copper from its ores is due to J. Hollway.

When metals are abstracted from their ores by fusion, the necessary heat is generally obtained by the burning of coal, coke, or other form of carbon. But sulphides are combustible substances, and can be made to burn in air; while oxides are bodies that have been already burnt, or entered into combination with oxygen. J. Hollway has shown that metallic sulphides can be utilized as sources of heat in certain metallurgical operations.

The most important of mineral sulphides is pyrites. The predominating constituent in this mineral species is bisulphide of iron, with which are frequently associated sulphides of copper and arsenic; silver and gold are usually present in larger or smaller quantities. When pyrites is roasted in the open air, an increase of temperature takes place in its mass, so that oxidation continues without the application of external heat. This operation is carried on in Spain and other countries,

where vast quantities of cupreous pyrites are exposed in heaps for several months to a slow process of combustion, which gradually resolves the sulphide of iron into ferric oxide. A similar combustion is effected in the pyrites burners of the sulphuric acid manufacturers, the solid product of the operation being known as burnt ore, an impure peroxide of iron. Sulphuretted ores of copper, lead, and zinc, are usually roasted to render them reducible in the furnace, and to make those other constituents which are of little value capable of combining with the fluxes used, the requisite heat being always obtained by the combustion of coal or similar materials.

This process of roasting extends over a considerable space of time, and the heat evolved by the oxidation of the sulphides is never very manifest at any period of the operation. The sulphur and metals frequently burn to waste, because the utilization of the heat resulting from the burning of such fuel has not been fully considered. If a rapid current of air is forced through molten sulphides, the maximum temperature of the combustion is attained, because all the oxygen of the air driven into the mass is then used for oxidation, and the operation is concentrated into the space of a few minutes, instead of occupying, in the case of cupreous pyrites, many months. Hollway has found that the oxidation of sulphides would produce sufficient heat to render their smelting a self-supporting operation, by forcing a current of oxygen from a gas cylinder into the molten sulphide, contained in a fireclay crucible, with tuyères. In further experiments, the sulphide was acted upon by a current of air, sand being added during the oxidation. A regulus and a slag were obtained. The sulphide of iron was made by fusing cupreous iron pyrites in a steel melting-furnace, the fire of which was allowed to burn down as soon as oxidation commenced; when the blast was turned on, the tuyères were dipped into the contents of the crucible, and the blowing continued for thirty minutes. Although the whole of the oxygen was probably consumed, yet the oxidation had not proceeded far enough to concentrate the regulus to any extent. About half the iron was removed as ferrous silicate, containing ·104 per cent. of copper, and the separation of the poor regulus from the superincumbent slag was very distinct. A further trial was made with the Bessemer converter, the plant employed consisting of an ordinary cupola, 4 ft. diameter at the tuyères, and copper 5 ft. above, having eight tuyères, four being 3 in. in diameter, and the remainder 4 in. in diameter. A ladle was used for conveying the molten metal to the Bessemer converter. The Bessemer converter was capable of treating 6 tons of crude iron at a time, and was lined as usual with gannister, and supplied with cold blast.

The engines for supplying the blast had two cylinders of 42 in. in diameter, and 4 ft. stroke, working at about 45 revolutions a minute, at an average pressure of steam in the boilers of 73 lb. per sq. in. The pyrites was put into the cupola with coke and treated like pig iron. When at each operation the cupola was tapped, the molten protosulphide was run into a ladle, and thence into the converter. With this plant, protosulphide, containing 3·4 per cent. of copper, yielded after fifteen minutes' blow a regulus containing 46 per cent. of copper. The destructive action upon the gannister lining was gradually mitigated by throwing sand into the converter. In another experiment, the pyrites used contained 2 to 3 per cent. of copper, 1·5 oz. of silver and 3 grs. of gold a ton; owing to the small quantity of protosulphide employed in each of these experiments, the blowing was of very short duration, and over blowing had to be avoided, but in operating with larger quantities of protosulphide there is not the same difficulty. With another blow occupying seventeen minutes, 14 cwt. of red sand were added. The main pressure of blast was 20 lb. a sq. in. The blown product of the experiment was emptied into ingot moulds, and allowed to cool. When cold it was found to consist of three zones, the top one being the slag proper, the central zone a mixed product of slag and regulus, and the last the regulus free from slag. The specific gravity of the regulus was about 4·8, and the slag about 4·1. The products of the experiment gave upon analysis, for the protosulphide, sampled as it ran from the cupola, 59·62 per cent. of iron, 3·52 per cent. of copper; the slag, 53·3 per cent. of protoxide of iron, peroxide of iron 3 per cent., iron combined with silver 5·79 per cent., copper combined with silver 0·16; the mixed regulus and slag, iron 55 per cent., copper 5 per cent., silver 10·41 per cent., silica 12·70 per cent.; the regulus, iron 57·10 per cent., copper 15·81 per cent. The temperature of the gas at the mouth of the converter was 157° C. one minute after the blast was turned on, and rose to 703° C. at the end of fourteen minutes. In some cases the zones were not horizontal, but more or less conical, as, owing to sudden refrigeration of the mass, the denser particles subsided last in the centre portion, which remained fluid longest. The lining of the converter after these blows was found to be not very materially acted upon, and therefore the reserved converters were not required.

Hollway recommends that the form of the furnace should be a modification of the ordinary blast furnace, fitted with a tuyère hearth. Such a furnace, built on pillars, with boshes and hearth of some substance not rapidly acted upon by the slag formed during the burning of the sulphides, would, working continuously, treat a large quantity of material. Being built on pillars, the crucible hearth and tuyère bottom could be replaced when necessary, without disturbing the remainder of the structure, and as these would be the only parts in contact with the fused materials, the furnace from the boshes upward should not experience much wear and tear. When a gannister lining similar to the ordinary Bessemer lining is employed for the boshes and hearth, the corrosive action of the protoxide of iron would be neutralized and avoided by introducing with the pyrites sufficient siliceous material to produce a slag containing at least as large a proportion of silica as compared with the bases, as the formula $2\,RO, SiO_2$. If, however, a basic lining is employed, the slag should contain less silica, and in no case more than the proportion equivalent to the formula $2\,RO, SiO_2$. Under such circumstances the blowing would be continuous, the hot charge coming down to a fusion zone, the height of which over the tuyères would be determined by the amount of air blown in, and the frequency with which the blown products are withdrawn, varying likewise with the composition of the charge. The products would be withdrawn by tapping, as with a common blast furnace, the regulus being run off from a reservoir below the tuyères, where it would collect, and being thus unacted upon and undisturbed by the blast, rich regulus, or even metallic copper could be produced. By continuing the oxidation, and producing Cu_2S, and some metallic copper, the gold and silver

would be found with the metallic copper. It is well known that small quantities of silver and gold are far more completely extracted from minerals by smelting, or the treatment of fluid metal or metallic regulus, than by any wet process. The fact that by such methods practically the whole of these metals present are collected and concentrated, is the fundamental principle of the analytical assay, and is proved by the accuracy of determinations made in this manner. A large side flue, at the top of the furnace, Fig. 957, would carry off the gases and sublimates after their temperature had been reduced in heating the charge, introduced above through a self-closing hopper. Such a furnace, 30 or 40 ft. high, with a hearth capacity of 1 cubic metre, would be capable of treating annually 50,000 tons of pyrites and a similar quantity of silecious fluxes, working 200 days in the year.

The theory of smelting sulphides with a blast furnace is as follows;—The operation is started by placing the tuyère hearth in its place, and throwing in hot coke at the top of the furnace. The blast is now turned on, and the coke develops a high temperature by its rapid combustion; the ordinary working charge of sulphides and fluxes is now introduced at the top hopper, and as the sulphides melt the coke burns away. As soon as a layer of molten sulphide lies over the tuyères the blast is increased, and also the burden of the furnace. The charge above the fusion zone, as it descends, is gradually heated, losing much of its sulphur by volatilization before it becomes molten. On fusion, a considerable amount of lead sulphide will distil over, accompanied by the remainder of the arsenic as sulphide, in the strong current of nitrogen and sulphurous acid. These gases, as they pass upward in the furnace, will be greatly reduced in temperature by the volatilization of the sulphur and moisture from the crude materials. There is some reason to believe that more than half of the sulphur in pyrites is volatilized in the free state by this operation. The sublimed oxides, sulphides, and sulphur, would be collected in the wide chambers with which the side-flue is connected. Below in the hearth, the oxygen of the air forced in acts upon the sulphides of iron and zinc contained in the charge, and as long as a constant supply of these substances arrives at the hearth no other constituents present will be appreciably oxidized. A tap-hole near the top of the hearth allows the slag to be withdrawn. The blowing would be continuous day and night, so long as the tuyère hearth lasted; and the heat from the gases after they leave such a furnace could be utilized so as to heat the blast, or to produce steam-power for the blowing engines. The produce of about 6 tons of material would be tapped every half hour, so that in seven days' work 1000 tons of pyrites would be treated. If desired, the products could be run direct in suitable reverberatory furnaces, when, after the regulus had subsided, the slag could be run off while yet in a molten state, and in which the oxidation of the regulus could be completed. It is difficult to see how the charge could be overblown, but if it were, the product could be worked up again by adding it to a subsequent charge of sulphides, introduced at the top.

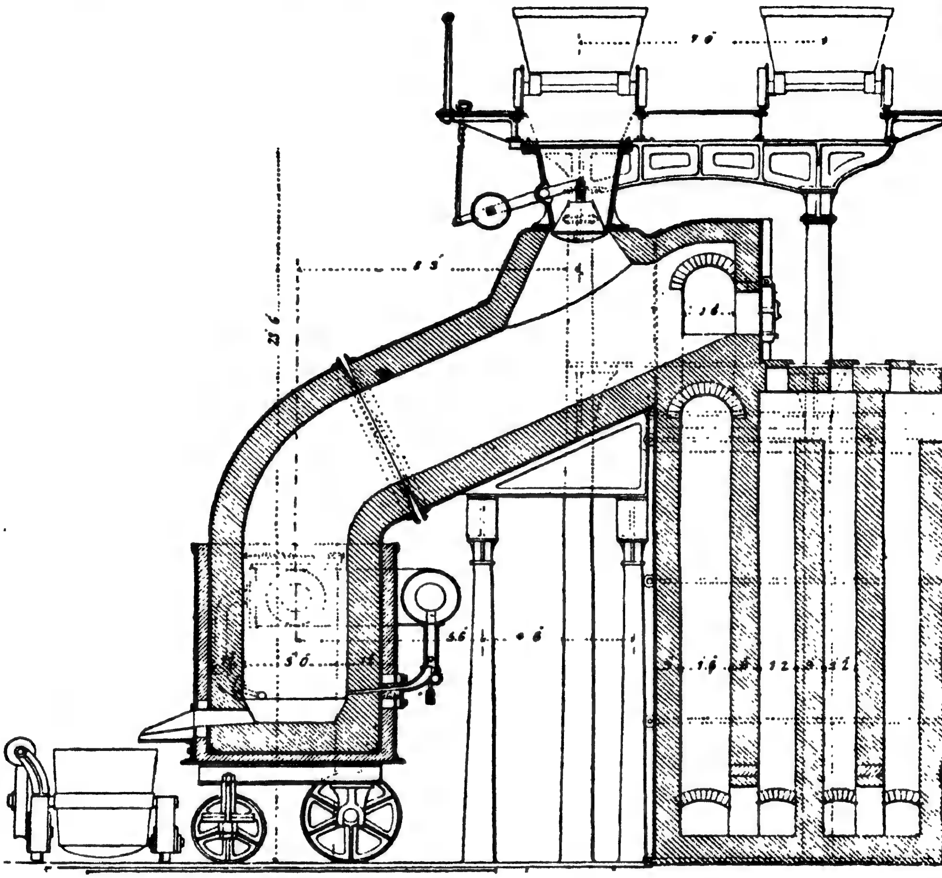
The sulphurous acid evolved could be oxidized into sulphuric acid in chambers, or reduced to sulphur by sulphuretted hydrogen. The latter decomposition might be accomplished by driving superheated steam into the furnace where the sulphides are oxidized. The sulphurous acid could also be utilized by Hargreaves' process, and there are other possible methods of treatment, such as dissolving the sulphurous acid in water by spray jets in towers, or by condensing the gas to the liquid state. Large quantities of liquid anhydrous sulphurous acid can be produced, from which sulphuric acid, free from arsenic, could be made. The gases, freed from impurities mechanically carried over with them, are first cooled and then led into towers, or other suitable vessels, filled with charcoal, which will absorb and retain the sulphurous acid, and allow the nitrogen to escape. The sulphurous acid is afterwards obtained from the absorbent by exhaustion or heat, and, being thus practically free from nitrogen, can more readily be liquefied by compression than is possible in the presence of a large quantity of that gas. The sulphurous acid having been extracted, the charcoal will be ready for another operation, and may thus be used many times in succession.

The following are calculations for working in Spain of 300,000 tons of pyrites, containing not less than $1\frac{1}{2}$ per cent. of copper. The coal necessary to produce the cold blast would be about 20,000 tons, and further 11,000 tons to heat it to 1000° F. One ton of pyrites contains, say 90 per cent. FeS_2, and 1·5 per cent. of copper. $0\cdot90\ FeS_2 = \cdot66\ FeS$, of which ·60 has to be oxidized. Of the remaining ·06 FeS, ·03 passes into the slag as iron protosulphide, probably combined, and ·03 is left with the regulus. Under these circumstances the regulus will contain upwards of 30 per cent. of copper. Thus $\cdot030\ FeS + \cdot015\ Cu = \cdot045$ of regulus, containing ·015 Cu, or $33\frac{1}{3}$ per cent. 0·60 FeS requires ·327 O for the reaction, $FeS + O_3 = FeO + SO_2$. Oxygen exists in air in the proportion of 23·5 per cent. by weight. Therefore, $23\cdot5 : 100 : \cdot327 = 1\cdot391$. Or 1·391 tons of air are required a ton of pyrites; 1·6 tons has been calculated upon to ensure an excess. Assuming that 1·6 tons of air are required a ton of pyrites, the amount of air to be blown in will be 480,000 tons a year, and reckoning 50 weeks of 160 hours each as working time, this is equal to 1 ton a minute of air required. This equals 29,300 cub. ft., and would be blown by engines whose blowing pistons have a collective area of 11,309, with a piston speed of 374 ft. a minute. When blowing 25 lb. blast, the average pressure is 17 lb., therefore $\frac{11,309 \times 17 \times 374}{33,000} = 2178$ indicated horse-power, and adding 10 per cent. for the friction of the engine, 2395 indicated horse-power. If the engines were of the compound type, so as to ensure economy, they would not use more than 2 lb. of coal an hour an indicated horse-power. This equals $2395 \times 2 = 4790$ lb. $= 2\cdot13$ tons an hour, and in 8000 hours a year, 17,040 lb. This, the very least that should be calculated upon, would probably in practice reach 20,000 tons a year. Each indicated horse-power would require, say 22 lb. of water to be evaporated an hour, or for 2395 horse-power 52,690 lb. of water an hour. Each square foot of bolier-heating surface would not evaporate more than 5 lb. of water an hour, therefore 10,538 square feet of heating surface would be required, and this should be contained in, say, 20 boilers of ordinary size.

Figs. 957 to 959 are of an arrangement of plant for treating 300,000 tons of cupreous pyrites by

Holloway's process. Fig. 957 is of a converter for treating cupreous pyrites by this process. Fig. 960 is a section on the line A B, Fig. 958. Fig. 959 is an extended section on the line C D. *a a* are the depositing pits, *b* the furnace, *c* the bunkers, *d* the sulphur-collecting chambers, *e* the blowing cupolas, *f* siding and tramway for empty ladles, *g* hot-blast stoves, *h* sulphur-depositing chambers, *i* reverberatory furnace heated by gas, *j* the hot-blast main.

957.



It is estimated that by this process 300,000 tons of pyrites, containing not less than 1½ per cent. copper, 1 oz. 11 dwts. 8 grs. silver, and 3 grs. gold a ton of pyrites, should produce 15,000 tons of regulus, containing 30 per cent. copper, 15 oz. 13 dwts. 8 grs. silver, and 1 dwt. 6 grs. gold, a ton of regulus; but the quantity is somewhat less, because there is a small loss of copper in the slag, which, however, should not exceed 10 per cent. of the total copper.

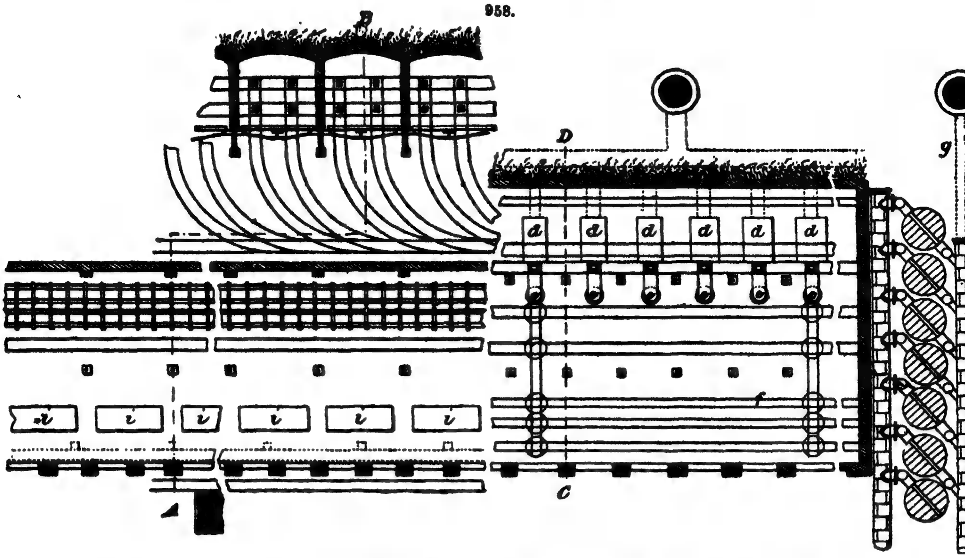
300,000 tons of pyrites would also produce 72,000 tons of crude sulphur, and there would be expended on 310,000 tons of pyrites 18 tons of coals for every 100 tons of pyrites.

If ordinary sand or siliceous rock is employed, 1 ton will be required to every 3 tons of pyrites. In these calculations, however, an extreme case is preferred, that the silica might be taken from the linings of the vessel, and therefore a larger quantity must be calculated upon, as sand cannot be used alone for the linings. 150,000 tons are therefore estimated as the quantity required. The substances volatilized consist of varying mixtures of arsenious sulphide, lead sulphide, and oxide of zinc, also sulphide of the latter metal. There may be also small quantities of sulphide of thallium and oxide of iron, which may, for practical purposes, be neglected. Sulphur and sulphide of arsenic are readily vaporized in a current of non-oxidizing gases at a low red heat, 500° C., while sulphide of lead, as also oxide and sulphide of zinc, distil very slowly under similar circumstances. The greater part of the zinc and lead is found in the first sublimate chambers, while the sulphur and arsenious sulphide deposit further on. 300,000 tons of pyrites would also produce, in addition to about 72,000 tons of crude sulphur, about 120,000 tons of sulphurous acid.

The cementation process is at present employed in Spain, by which about 85 per cent. of the copper from pyrites is obtained, about 65 per cent. by lixiviation in the tanks, and 20 per cent. afterwards from the resulting residue, the remaining 15 per cent. of the copper being practically lost. The sulphur passes into the air as sulphurous acid causing great damage to property, besides the entire loss of the sulphur. This process is only employed for treating the poorer ore raised from the pyrites mines, and is carried on in their vicinity. It is divided into three principal operations,

calcination, lixiviation, and precipitation, and was first introduced at the Rio Tinto mines by De Garcias, in 1661. On the whole, it is very suitable for the treatment of the poorer pyrites ores for copper. It does not require much skill on the part of the labourer, nor does it involve the use

958.



of any very costly materials or complicated appliances. The cost when the process is intelligently carried out, is moderate. These, doubtless, are no slight advantages, but the process has many disadvantages, especially when large quantities require to be dealt with. It seldom happens that

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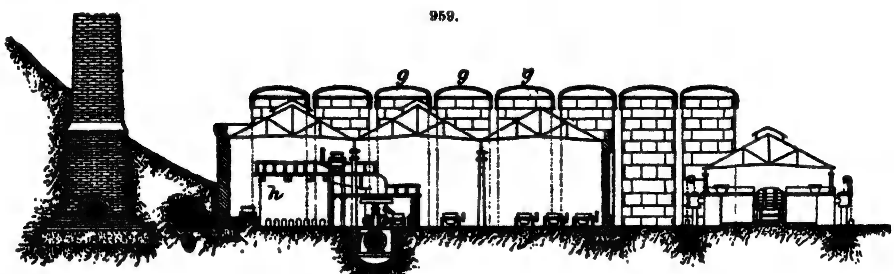
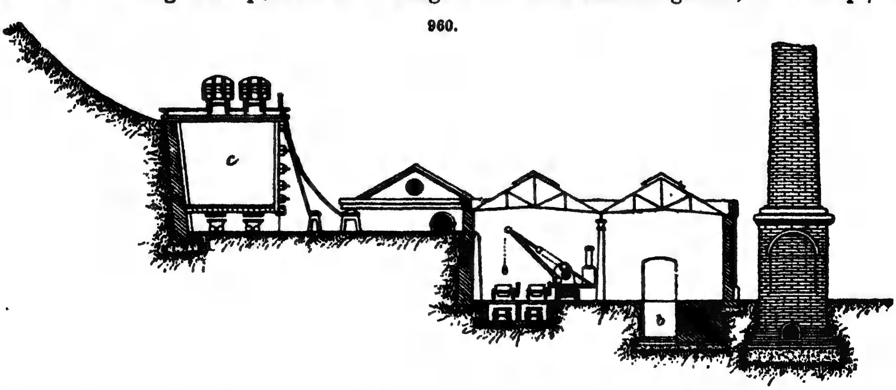


an ample supply of water can be obtained from any source, and, in consequence, the works are often stopped, wholly or in part, for several months yearly. When rain falls it usually comes in large quantities. During these periods the drainage from the calcination ground, waste heaps, and

960.



mineral stock heaps, is highly impregnated with copper, and is so great that it cannot be overtaken in the precipitating tanks, so that much copper is lost. The fume from the calcination of such large quantities of pyrites impregnates the air for miles around, and completely destroys all vegeta-

tion within its influence. The works at all times are more or less affected, and the suspension of some part of the process takes place with more or less frequency. Only the copper in the ore is available, the iron, sulphur, gold and silver, which form about 98 per cent. of the mineral, is either lost altogether, or, at least, rendered useless for any practical purpose.

The process being suitable only for the poorer ores, cannot be advantageously applied to richer ores, containing from three to four per cent. of copper and upwards. Government and local authorities are averse to the extension of the process to districts where it is not now in use, on account of the evils arising from the fumes and the pollution of streams, so that its use in Spain is restricted to situations where it is already established. In Portugal it is prohibited altogether. The works are scattered over a large area, and the entire method embraces many separate operations, from the time the crude ore enters the calcination ground to the exit of the finished product. During the whole of this time, about twelve months, it is subject to many influences which sensibly tell as a loss on the narrow margin there is for working upon. Rain, leakage, imperfect calcination, lixiviation, and precipitation considerably affect the working costs, and necessitate on the part of those in charge continued watchfulness and vigilance. A slight neglect to either of these details may make all the difference between a profit and a loss on the operation. The apparent simplicity of the whole seems to have a wonderfully fascinating influence on such as come in contact with it for the first time, or who have only an indirect connection with its working. The conditions favourable for obtaining the best results can by no means be secured at pleasure, by simply adopting certain fixed rules and practices; conditions incident to the system prevent the adoption of fixed mechanical routine. Anything which would shorten the process, reduce the number of operations, and the area occupied, would be a great step in advance, and the importance of this subject may be estimated from the fact that one and a half to two million tons of pyrites are raised annually by the Rio Tinto Company, the Tharsis Company, and the firm of Mason and Barry. In South America, Cuba, Australia, Cape of Good Hope, and in many other places, there are large quantities of poor copper ore containing 5 per cent. and upwards of copper, which are thrown aside as unsuitable for smelting on account of the cost of fuel, and from which the copper is only partially extracted by the cementation process.

By Holloway's process the whole of the oxygen of the air, driven into a thin stratum of protosulphide of iron, FeS, is utilized for oxidation. The heat evolved in the rapid oxidation of sulphides and without the use of extraneous fuel other than that employed in producing the blast, expels about one-half of the sulphur contained in iron pyrites, FeS_2, in the free state. The remainder of the sulphur, excepting that left with the regulus, is principally evolved as sulphurous acid. Although only about 20 per cent. of sulphur is oxidized, the proportion of sulphurous acid to nitrogen by this process is 14·9 per cent., which is a larger proportion of sulphurous acid than is obtained by copper smelters who manufacture sulphuric acid. In the ordinary method of burning pyrites, where 45 per cent. of sulphur is oxidized, the ratio of sulphurous acid to nitrogen is only 16 per cent. The volatile metallic sulphides, such as arsenic sulphide and lead sulphide, are distilled off with the sulphur. Iron being more oxidizable than copper, silver, gold, nickel, and certain other metals, these latter will be all concentrated in the regulus, provided an excess of sulphide of iron is always present. The protoxide of iron thus formed is converted into slag by the addition of the silica introduced with the pyrites. The more perfect fusion of the slag thus obtained prevents loss of copper by entanglement with imperfectly fused material. About 16 to 20 per cent. of incombustible material, having a specific heat of ·15 to ·25, can be added to a ton of pyrites when a cold blast is employed, assuming that 1000° C. is the temperature for the operation. The quantity of similar incombustible material can be increased to from 30 to 34 cwt. to each ton of pyrites operated on, when a hot blast of 500° C. is employed, assuming that 1000° C. is the temperature necessary for the operation. Such incombustible material may contain larger or smaller quantities of valuable metals, as oxides, which will pass into the regulus or be volatilized as sulphides, after double decomposition with protosulphide of iron present in the molten bath. Thus, silicates of nickel or copper would be converted into sulphide of nickel or copper, and be concentrated in the regulus. When employing a siliceous lining for the furnace, the corrosive action of the protoxide of iron formed is greatly mitigated, if not practically avoided, by the addition of sufficient silica with the charge of pyrites to produce a slag containing more silica than is required by the formula $2(MO)SiO_2$, M representing an atom of divalent metal. The quantity of coal necessary to produce the blast, calculated on the oxygen requisite for the oxidation which takes place, is $1\frac{1}{4}$ cwt. a ton of pyrites. To heat the blast to 500° C. an additional amount of less than 1 cwt. of coal a ton of pyrites is sufficient.

DOCKS.

For the purpose of affording access to the immersed parts of vessels, there can be little doubt that, in the early periods of navigation, the vessels were either hauled up on the beach for examination, in the absence of rise and fall of tide, or, where there was a considerable rise and fall of tide, the vessel was placed over a flat beach at high water, and allowed to ground as the tide fell. Although the latter plan is easy of application, and useful to a certain extent even for large vessels, where there is a considerable rise and fall of tide, the former mode must have been difficult to carry out except with very small vessels, and therefore it is probable that the plan of careening was resorted to as soon as vessels were built of any considerable size.

This plan, more properly called heaving down, was carried out in two ways; either by bringing the ship near a quay wall provided with mooring rings and capstan, and attaching ropes to the heads of the masts, so as to haul the ship over into a horizontal position on the water; or by putting the heaving down tackle on board another vessel, so that the operation could be performed independently of the land. This second plan had the advantage of being also independent of the rise and fall of the tide, which in the other method of course affected the position of the ship under repair.

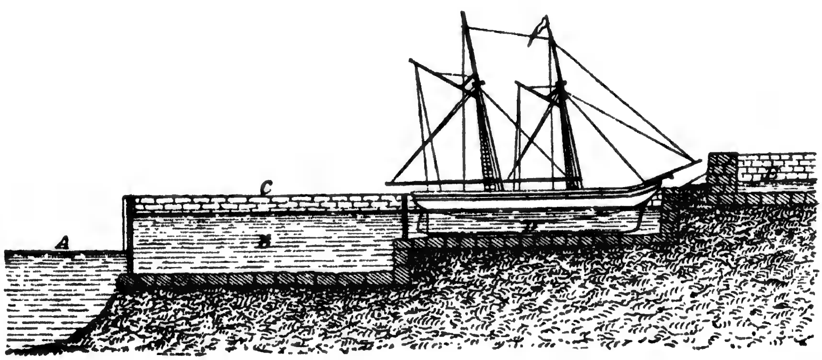
The plan of careening seems to have been extensively practised in the naval arsenals of France

at an early date. Whether done by tackle from the land or from a vessel afloat, the operation was of course aided by the removal of the ballast and heavy weights, so as to lighten the ship. By the mere shifting of the weights, and without the assistance of tackle, a large amount of the ship's surface could be exposed; but this plan was of necessity attended with considerable danger of foundering, as exemplified in the fate of the 'Royal George,' which foundered at Spithead in August 1782, with upwards of 600 persons on board, whilst being careened. Careening is also stated to have been the cause of permanent distortion in the shape of vessels, from the exposed side being strained to an unnatural degree of convexity prior to the driving in of the caulking, which then kept the vessel to the distorted figure it had assumed.

The next mode is the ordinary graving dry dock, which even at the present day is the plan most commonly employed in Europe, and will probably continue to be preferred in places where there is a large rise and fall of tide, and where the ground is suitable for excavation. In many parts of the world the rise and fall of the tide are sufficient to admit of a very large vessel being drawn into a dock at high water, so as to be brought over the keel blocks, on which it then settles down as the tide recedes, and at low water the dock is left dry and the vessel exposed for repairs; the sluices being then closed exclude the water, so that the succeeding tides cause no interruption to the work. But in situations like the shores of the Mediterranean and in other places where the tide is but small, the water has to be got out of the dock by pumping, which before the days of steam power was found both an expensive and a tedious process, causing great delay before the vessel could be reached even for slight repairs or merely for inspection. To make the operation more expeditious, large chambers have in some instances been provided, below the level of the dock, sufficiently capacious to receive from the dock the whole or the greater part of the water contained in it, which could afterwards be pumped out of them at leisure. This plan gave the advantage of speed in emptying the dock, but it added largely to the first cost, and moreover caused the labour of pumping to be increased, owing to the greater depth from which the water had to be drawn; nevertheless these chambers were in use at Toulon and also at Portsmouth, notwithstanding that at the latter port there is a rise and fall of about 10 ft. at ordinary spring tides.

Where there was a lofty shore and a supply of water from a high level, it has several times been proposed, and amongst others by Belidor, to make dry docks as shown in Fig. 961, where A represents the ordinary sea level, and B a low-level dock opening into a basin in connection with the sea,

961.



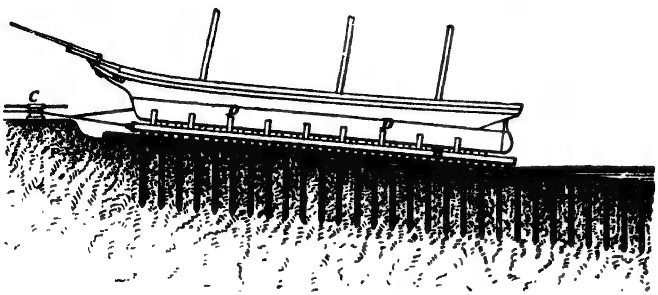
and having its sides C as much above the sea level as would equal the draft of the largest ship to be docked. D is an upper dock, having the top of its sides level with C, and its floor a little above the sea level A. If a ship be floated into the lower dock B and the gates be then shut, and if water from a high level E be allowed to flow into B and D, the water will continue to rise and the ship will be lifted until its keel is high enough to pass over the blocks on the floor of the upper dock D, when it can be hauled into that dock and the sluice of the lower dock B opened so as to allow the water to escape into the sea, leaving the ship securely berthed in the raised dock.

In some few favourable situations graving docks are comparatively simple to construct and maintain, namely, in such situations as Birkenhead, where the docks are hewn out of the solid rock, which while it is sufficiently hard and homogeneous to support the heavy weights, is sufficiently soft to be readily worked. In these cases there are none of the dangers to be apprehended of settlement or of blowing up the bottom, that exist where the dock is built in an excavation made in the earth, which is frequently of an extremely treacherous character at river sides. As regards the mode of closing the entrance to dry docks, this has been effected either by gates to open sideways like those of a lock, or to fall upon the bed of the river, or by caissons. The latter, now that the introduction of iron for ship-building purposes has admitted of their being made of that material, are almost universally adopted for large docks, and have the advantage of affording the means of retaining water inside the dock as well as of keeping it out, which is of considerable importance for allowing time enough to adjust the ship properly before it settles down on the keel blocks. Among the largest graving docks may be mentioned the double dock at Brest, 721 ft. long and 92 ft. wide, with 35 ft. depth of water over the sill; and the double dock at Portsmouth, which is 636 ft. long, 88 ft. wide, and 27 ft. deep over the sill; and one of the largest single docks is that at Devonport, which is 415 ft. long, 73 ft. wide, and 32 ft. deep over the sill.

The hauling up of ships appears to have been practised from a very early period in the Venetian arsenals, and also at Toulon in France, where it was applied in 1818 to a large vessel; but the ships

seem to have been only brought over an ordinary building slip, and then hauled up on the ways, being steadied by a sort of sliding cradle.

A special construction of carriage for this purpose was invented in 1818 by Morton of Leith, Figs. 962, 963. An inclined slip-way A is formed on a slope of about one in twenty, and provided with rails on which travels the wheeled carriage B, the railway extended sufficiently below the water to admit of the ship being floated over the carriage. By then hauling up the carriage by the chains and capstan gear C, the ship, being attached to the chain, is drawn up out of the water and above the influence of the highest tide, and is blocked up upon the floor of the slip from heeling over while in the act of being hauled up; the carriage is provided with bilge blocks D sliding on



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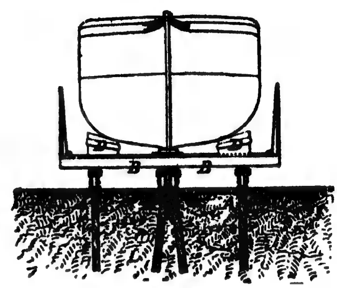
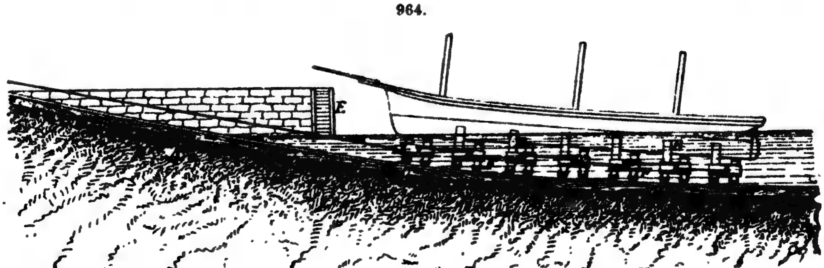


timbers transverse to the slip. As the ship settles down on the keel blocks and before she is removed from the water, these bilge blocks D are hauled in until they support the bilges, the hauling being done by ropes led up to the deck of the ship. This appears to have been the first use of proper bilge-block shores which could be applied while the vessel was still afloat; and F. J. Bramwell states in his papers, 'Trans. Ins. M. E., 1861,' from which we have taken much of the information in this article, that such a mode of sustaining vessels at the bilges before the water support is taken away is of the greatest utility, on account of its importance in preventing undue straining or risk of heeling over. In ordinary graving docks, it is true, bilge shores are used; but they are not applied until the water has been removed from the dock, and therefore not until after the ship has been subjected to the strains arising from the weight of her contents without her natural water support.

Morton's slips were at first intended only for small vessels, but they have been constructed for ships of 2000 to 3000 tons burden. With small vessels little difficulty was experienced in building the slips, especially where there was a considerable rise and fall of tide, because the lower part of the slip could be constructed at low water; but when the longer modern vessels were required to be taken up, the length of the slipway below the water became very great, as a slope of one in twenty requires the length of slip below water to be twenty times the draft of the vessel, merely to reach her stem, and the slip must then be carried still farther to extend under the length of the vessel. As this portion had to be constructed by the aid of divers, and its execution was attended with serious difficulty, it has been proposed to shorten the slip in the three ways combined in Fig. 964. The first

964.



plan is to make the slip of a curved form, giving a steeper slope to the upper portions of the slip, so that the length below the water line is not so great as if the slope had been continued uniform up from the bottom end; the second mode, intended for places where there is a rise and fall of the tide, is to enclose the upper part of the slip within water-tight walls and to employ gates for shutting out the water, and the third plan is a telescopic construction of the cradle on which the ship is lifted.

In Fig. 964 the ship is partially raised, and with all the lengths of the telescopic cradle fully drawn out. A A represents the surface of the slip made to a curve; E the gates, placed just below where the vessel will be when fully hauled up; B the telescopic cradle, composed of lengths attached to each other by rods F, so that when it is lowered it may rest at the bottom of the slip collapsed to about one-half its full length. As soon as the stem of the vessel takes its bearing on the first section of the cradle and the hauling commences, this first section is drawn out from the

second to the full extent of its coupling rods, and the second is then drawn out from the third, and so on; the result being that the vessel is securely taken up on a cradle requiring no greater length of slipway below the ship than half of the length of the ship. By these various contrivances the length of the slip has been considerably shortened from what it would have been if constructed on the original system unaltered; but as regards the dock-gates and the water-tight side walls, it may not unfairly be said that their use is inconsistent with the employment of a simple slip, nor indeed could they be resorted to in a tideless sea, without the expense of pumping apparatus to empty the upper part of the slip.

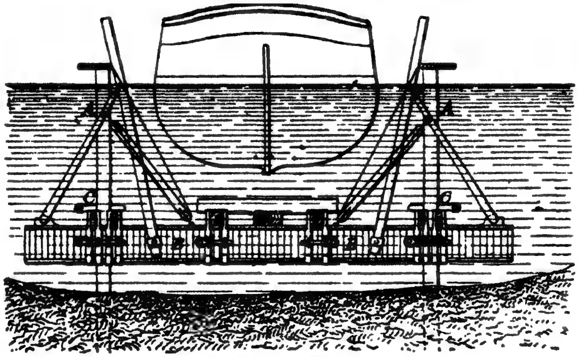
The application of this slip to vessels of a larger class rendered some improvement necessary in the simple hauling chain that had sufficed for ships of 200 tons. A set of traction rods was first substituted for the body of the chain, and was hauled in by a short flat-linked chain working over a pitched wheel driven by gearing. The end of this flat chain was first attached to the foremost rod, and then hauled in until the second rod was brought up to the place of the first, when the flat chain was overhauled and made fast to the second rod; and this operation was repeated with the successive traction rods until the ship was fully drawn up. A further improvement consisted in making the flat-linked chain endless, so as to avoid the necessity of overhauling it. For some time past, however, the larger slips that have been erected have been worked by the direct application of hydraulic rams to the ends of the traction rods; and among other plans double presses have been employed, made to work alternately, so that the hauling up might be nearly continuous.

An important adjunct to the slip is an arrangement of transverse lines of rails in the building yard, at the upper end of the slip, so that, by the use of carriages, the vessels hauled up can be shifted sideways, thereby enabling a single slip to serve for hauling up several vessels in succession, so that their repairs may be going on at the same time.

The simple plan already mentioned of placing a ship on a beach at high water, that it may be left dry at the ebb, is still in use where there is a considerable rise and fall of tide; and to enable it to be carried out without risk of unequal support to the ship, a regular open framing of beams is made on the beach, called a gridiron, by means of which vessels can be blocked up, and properly examined and repaired at low water. There is the objection, of course, that at the rise of each tide the work has to be suspended; but nevertheless the system is so simple and inexpensive, and the vessels are so readily got off and on, that it continues to be employed.

In the plans previously referred to for lifting vessels out of the water, the vessels have been hauled up on an incline; and in the class of Direct Lifts, the earliest is that of Alexander Mitchell, who in 1833 proposed to raise vessels out of the water by the means in Fig. 965. Two parallel rows

965.



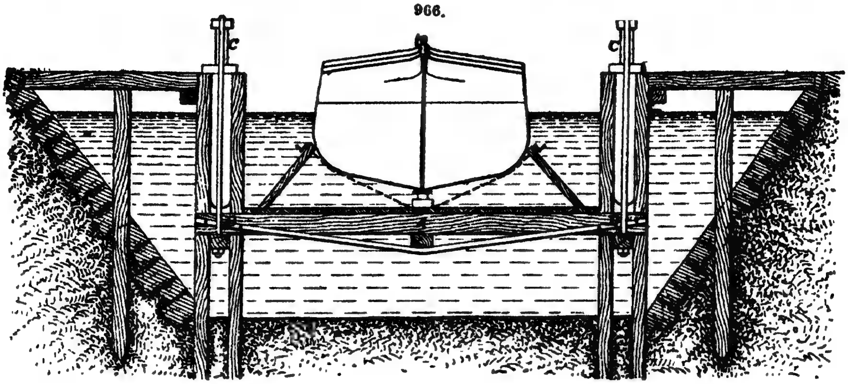
of piling A A are placed sufficiently wide apart to admit the vessel between them, and B B represents a permanently buoyant floor, made of light materials or of caissons. On the ebb of the tide this floor sinks between the piles, and at low water pins C C are fixed in the piles above the flooring. When the tide next rises the floor is held down by the pins, and at high water the vessel is brought over the floor and allowed to settle down on it, being maintained in an upright position by shores from the piles. At the next ebb the ship is duly propped up by bilge shores from the floor; and the side shores being then removed and the holding down pins withdrawn, the flooring is lifted by the next rising of the tide, taking up the ship with it, which rises and falls with the buoyant flooring at each tide until the repair is completed, when the flooring is again held down for the vessel to be floated off at the next high tide. This plan is evidently not suitable for cases requiring rapid access, as it needs at least three low and three high tides for enabling a vessel to be got on and off.

In 1827 a screw lift was constructed in America for raising vessels independent of the tide, Fig. 966. It consisted of a platform A on which the vessel was to be lifted, the ends B of the transverse timbers of the platform being steadied by two parallel rows of piles C C, placed far enough apart to admit the vessel between them. The longitudinal timbers which connected the heads of the piles carried a number of vertical screws, as many as forty-six having been used in one instance, the lower ends of which were connected to the transverse timbers of the platform, so as to raise the vessel out of the water. Since 1836, however, this lift has been worked by means of hydraulic presses. Fig. 967 is of the arrangement at work at New York in 1853. Chains, shown by the dotted lines, are attached to the ends of the transverse bearers B B of the platform, and pass over

pulleys to the long traction bars D, the land ends of which are connected to the hydraulic presses E for lifting the platform with the ship upon it.

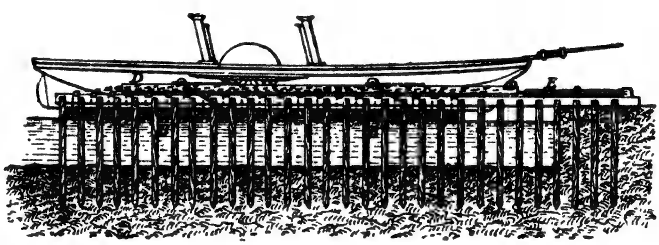
In 1842, an improvement upon the screw lifting dock was proposed by Robert Mallet, Figs. 968,

966.



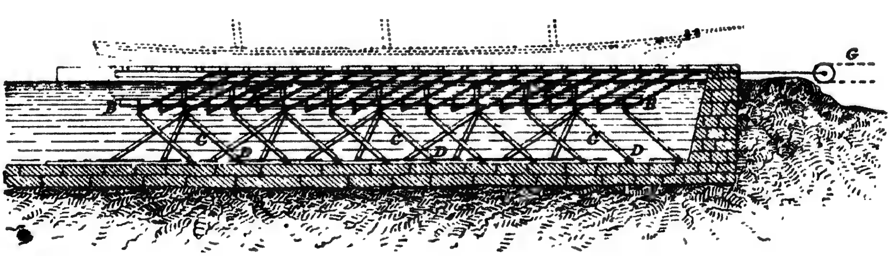
969. The framework B on which the ship is to be raised is carried on a number of supports C C, hinged at their lower ends to eyes D, supported on the rock or on piles, and at their upper ends to the frame B, forming a sort of parallel ruler motion. The slings E attached to the top of the supports C

967.



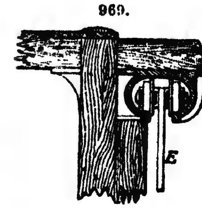
are provided at their upper ends with rollers, which run within a tubular rail F having a continuous slot on its under side, as shown to a larger scale in the section Fig. 969 ; and the slings are hauled in by the chains G, worked by powerful steam winches. The frame B being lowered and the ship

968.



drawn over it, the chains are then hauled in, so as to pull the slings horizontally, thereby raising the framing until the ship is lifted out of the water. This arrangement has the advantage of giving a nearly uniform strain on the chains and machinery throughout the lifting of the vessel, inasmuch as at the commencement, when the supports are nearly horizontal and carry but little of the weight, the slings are vertical and the weight of the ship is almost entirely carried by the water; while by the time the ship has lost the support of the water and the slings have become inclined, the supports have assumed a position more nearly upright, and therefore, although the whole weight of the ship has now to be borne by the lift, the proportionate strain coming on the chains is but small.

969.



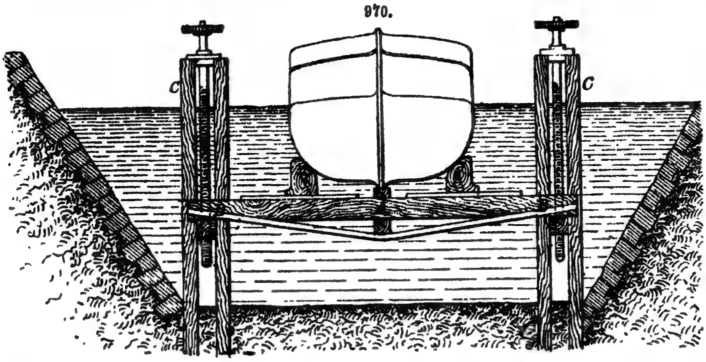
In the lift designed by Scott, Fig. 970, the ends B B of the cross timbers of the platform A, were attached to slings depending from the crossheads of a number of vertical hydraulic presses C C, the stroke of the presses being equal to the lift of the vessel. It was intended either to repair the vessel on the platform, or to move it off

on railways either endways or sideways, so as to make one lift answer for the simultaneous repair of several vessels.

The ship lift of Edwin Clark, at the Victoria Docks, London, has already been described at p. 1265 of this Dictionary.

It will be observed that in docking a ship by this process, the whole weight of the pontoon has to be lifted; that the ship has to be raised above the surface of the water to a height equal to the

970.

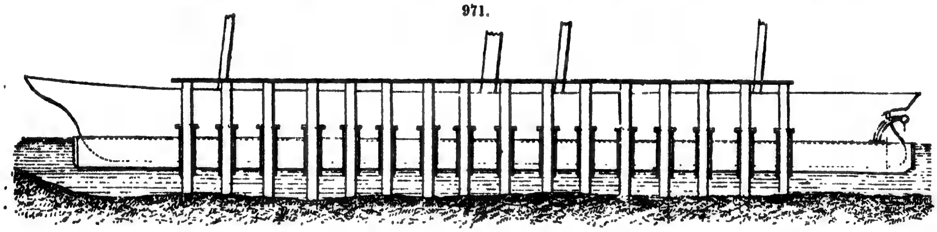


depth of the pontoon; and that the depth of water required over the top of the hydraulic lift girders is at least the depth of the pontoon, in addition to the draught of the ship, with a small allowance for clearance.

In consequence of the increased weight, length, and draught of ships at the present day, it became necessary to modify to some extent Clark's system of docking, so as to adapt more fully the appliances hitherto in use to present requirements in these three principal respects. To attain this object the floating dock, Figs. 971 and 972, was constructed by D. Halpin, assisted by Charles Elwin, and to the latter gentleman's paper in the 'Trans. Inst. M. E.' we are indebted for the following particulars of this work.

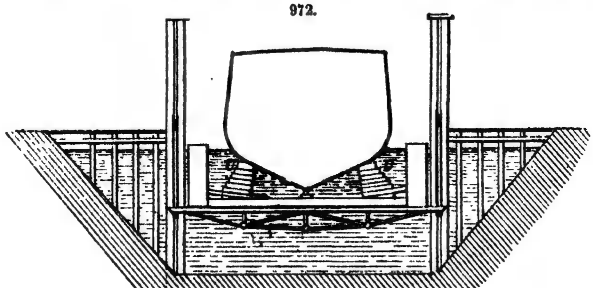
The floating dock Figs. 971 and 972 consists of two longitudinal box girders, forming the side walls of the dock, and connected together by eighty cross girders, the flanges of these being con-

971.



nected by plates to form the bottom skin. One end, called the forward end of the dock, is closed in permanently to the level of the top of the side girders; the other or after end is provided with a pair of wrought-iron hinged gates, of the same height, to allow ships to pass in or out. In the centre line of the dock, and between the cross girders, are short girders running longitudinally, and of the same depth as the cross girders. On the centre line of the dock, and on the top flange of each

972.



cross girder, is placed a timber keel block; and on the tops of the cross girders, at intervals as required, are placed timber bearers for carrying the bilge blocks. These last are mounted on sliding carriages. The box girders are divided into compartments, those in the centre of the dock being permanent air chambers; while the end compartments, which are filled when the dock is submerged,

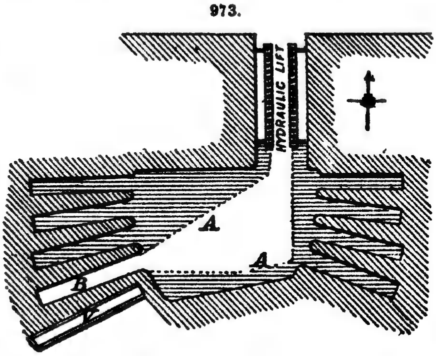
are used, when required, as water-ballast chambers, the amount of water retained in each chamber being regulated by a 6-in. sluice valve worked from the top. In compartments of the side-box girders, at the forward or closed end of the dock, two engines with centrifugal pumps are placed, one on each side, for pumping the water from the interior of the dock. The suction pipes from these pumps are of wrought iron, and are carried along inside the box girders as far as the centre of the dock, where they are brought out with cast-iron bends and bell mouths, extending down between the cross girders. There are no boilers on the dock, but the steam for the engines is conveyed from the boilers of the hydraulic-lift pumping engine by copper pipes as far as the timber platform, and then by a flexible steam hose, or swivel-jointed copper pipe, to copper pipes fixed on the dock and communicating with the engines. Entrance to the chambers where these engines and pumps are placed is effected by means of a wrought-iron trunk, the top of which is high enough to be above the water level when the dock is submerged. For letting the water into the interior of the dock there are two sluice valves of 30 in. diameter, placed in the box girders about the centre of the length of the dock, one on each side. These sluice valves are worked by vertical rods passing through the tops of the box girders. On the top of the box girders are placed at intervals several pairs of wrought-iron bollards, riveted to the top flange, for the purposes of mooring the dock or warping it across the basin. Ladders for passing down from the top flanges of the box-girders to the interior of the dock are provided at intervals, and those which are liable to be damaged by a ship passing into or out of the dock, are made to detach and fall back close to the box girders. For the purpose of lifting propellers or other heavy weights over the box girder, in order to remove them to the shops, a 20-ton crane is provided, and fixed in the port-side box girder near to the after end.

The general dimensions of the dock are as follows:—

	Ft.	In.
Displacement width of dock	58	10
Clear inside " "	47	6
Length of cross girders	48	2
Depth " "	2	6
Distance apart "	5	0
Depth from top of keel blocks to under side of bearers beneath dock	3	8
Length over all on centre line	409	6
Length inside " "	406	0
Length of main or side box girders	400	0
Depth " " "	15	0
Width " " "	6	0
Width of dock over all	59	6

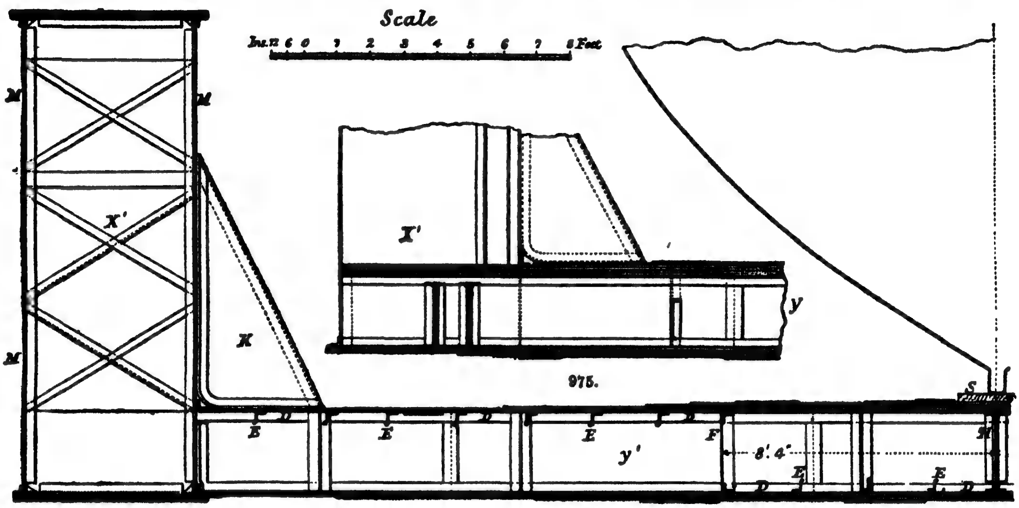
The process by which ships are lifted on the dock is a combination of the hydraulic lift and of the floating dock, and is as follows, Figs. 971, 972;—The dock having been brought in between the columns of the hydraulic lift, and fixed accurately in the required position, the lift girders are raised by the rams till they take sufficient bearing on the dock to prevent it from shifting. The two 30-in. sluice valves are opened, and water flows into the dock till it is level inside and out. The gates are then partly opened, and, the lift girders being gradually lowered, the dock descends till the water level is nearly up to the tops of the side girders, when the gates are opened right back, and the dock sunk either to the bottom of the lift pit, or low enough to give the required depth of water over the keel blocks. The ship to be docked is brought in over the dock, and the gates are closed. The dock is raised by the hydraulic lift till the keel blocks touch the ship, and raise it 6 to 12 in.; the bilge blocks are then drawn in by chains, and the lifting is continued till the tops of the side girders, gates, and closed end are about 12 in. out of the water. After this the gates are shut tight, the 30-in. sluice valves are closed, the steam connection is made with the pumping engines, and the docking or raising of the ship is completed by pumping the water from the interior of the dock, the hydraulic lift girders merely following up the dock, and keeping it in control. When the operation of pumping has been completed, the steam hose, or copper pipe, is disconnected, the hydraulic lift girders are lowered to the bottom, and the dock, with its ship upon it, is warped across the basin to its berth in the deepened bay B, Fig. 973. When all repairs or painting required to be done to the ship are completed, the dock is warped back again to the lift, and carefully fixed in position over the lift girders. These are then raised till they take a small portion of the weight of the dock and ship. The sluice valves are opened, and the water allowed to flow into the dock, which is lowered as it fills. When the water outside is nearly to the tops of the side girders, the lowering is stopped to allow the water inside to rise to the same level as outside. The gates are then opened, and the dock is further lowered till it is clear of the ship which is then hauled out into the Victoria Docks. The docking and undocking of the ship, having now been completed, the dock is raised on the lift girders, the water flowing out from the gates and sluice valves. When sufficient water has been drained out, the sluice valves are shut and the gates closed; and the lift girders being then lowered, the dock is left afloat ready to be prepared for another ship, or to be removed to its berth so as to leave the lift free for other operations.

973.



The floating dock as thus described, meets its three principal requirements in the following manner;—It enables the hydraulic lift to raise ships of increased weight, by supplementing it with the buoyancy caused by pumping out the water from the interior of the dock, the weight of the latter being almost entirely neutralised by the buoyancy of its air chambers. It enables the hydraulic lift to take ships of increased length, by means of its projections at each end beyond the lift. It enables the hydraulic lift to take ships of increased draught, by depending for its longitudinal strength upon the box girders, which are at the sides and not beneath the ship, and by thus not requiring under the keel any greater depth than is just sufficient for the transverse girders.

In order to determine what strength the structure would require, sample ships embodying extreme cases were taken for the calculations. Considerable difficulty being experienced in ascertaining the longitudinal distribution of weight in the ships, and also the distribution according to which this weight would be conveyed to the floating dock, it was determined to assume, for one



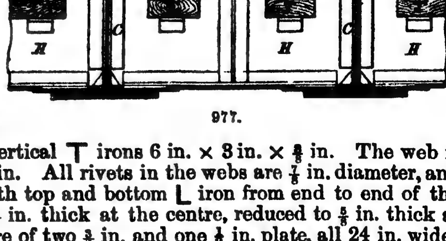
975.

974.

set of calculations, that the weight of the ship a foot run, at any part of its length, was proportional to its displacement at that part, and that the ship being perfectly flexible had no power of otherwise distributing its load. Other distributions of load were also assumed, so as to cover all possible cases.

With a view to enable the dock to take comparatively short as well as long ships, or to take ships having an unusually great proportion of their weight amidships, and to give a support to these ships coinciding as nearly as possible with the displacement at each section, portions of the flooring of the dock towards its ends are raised from the bottom to the top flanges of the cross girders, thus diminishing the end displacement; and, with the same object in view, the end compartments of the box girders are, when necessary, filled with water ballast of from 14 to 15 ft. in depth. The intermediate box girder chambers are, as already stated, permanent air chambers, which relieve the hydraulic lift of nearly the whole weight of the dock.

976.



977.

In consequence of the level of water over the hydraulic lift being at times so low as to leave a very small margin beyond the draught of ships to be docked, it was of the utmost importance that the cross girders should be made of the least depth possible consistent with strength and stiffness. The web C, Figs. 976, 977, is 2 ft. $5\frac{3}{8}$ in. deep by $\frac{3}{8}$ in. thick, consisting of three plates 11 ft. long, and two plates 7 ft. 7 in. long, stiffened with vertical ⊤ irons 6 in. × 3 in. × $\frac{3}{8}$ in. The web is united to the flanges by ∟ irons 4 in. × 4 in. × $\frac{1}{2}$ in. All rivets in the webs are $\frac{7}{8}$ in. diameter, and 4 in. pitch, the same pitch being maintained in both top and bottom ∟ iron from end to end of the cross girder. The top flange is 24 in. wide × $2\frac{1}{8}$ in. thick at the centre, reduced to $\frac{5}{8}$ in. thick at the ends. The bottom flange consists at the centre of two $\frac{3}{8}$ in. and one $\frac{1}{2}$ in. plate, all 24 in. wide; and one $\frac{1}{2}$-in. plate $35\frac{3}{8}$ in. wide, upon the projecting edges of which are lapped and riveted $\frac{3}{8}$-in. plates D D, connecting the flanges of the girders, and forming with them the flooring or bottom skin of the dock. These flooring plates, which form part of the bottom flanges of the cross girders, are stiffened with bulb ∟ iron girders 5 in. × $3\frac{1}{8}$ in. × $\frac{5}{16}$ in., weighing 10 lb. a ft. run, and placed 2 ft. apart centre to centre, at right angles to the cross girders, as shown at E E, Fig. 974. The rivets in top and bottom flanges of the cross girders are 1 in. diameter and 4 in. pitch. The rivets

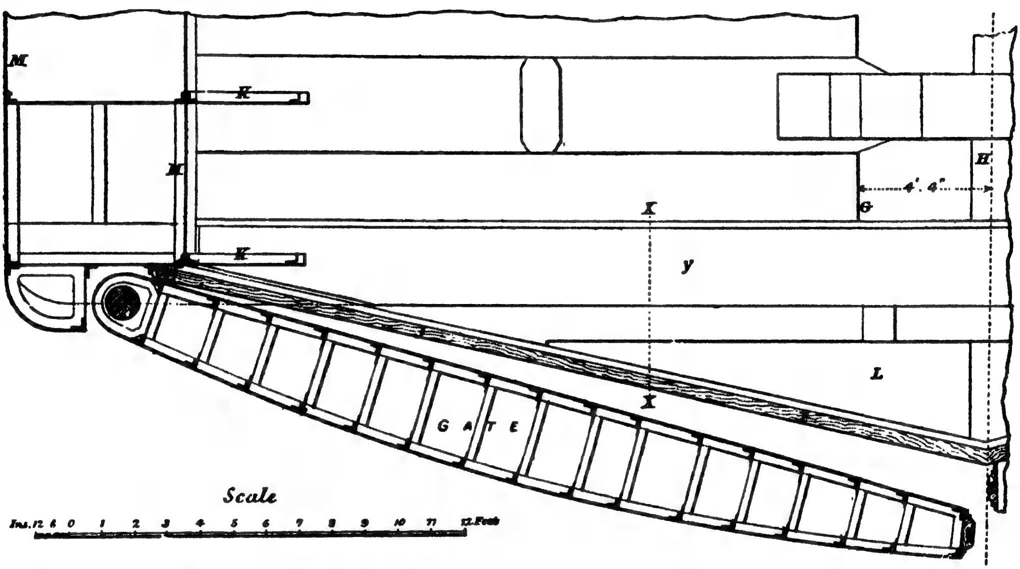
connecting the flooring plates to the flange plates are $\frac{3}{4}$ in. diameter and 3 in. pitch. These pitches are maintained from end to end of the cross girders.

At 105 ft. from the centre of the dock towards each end, the flooring plate D joining the flanges of the cross girders is removed from the bottom to the top flanges, excepting for a distance of 8 ft. 4 in. on each side of the longitudinal centre line of the dock; thus raising the water-tight skin of the dock at the sides of the flooring, but leaving a longitudinal trough in the centre, which is sufficiently wide to give access to the reduced section of the ships at this distance from amidships. heads F forming the sides of this trough, and the arrangement of the plates in the top and bottom flanges of the cross girders are shown in the transverse sections of the dock, Figs. 974, 975.

At 150 ft. from the centre of the dock towards each end, where the ship is still smaller in section, the longitudinal trough above mentioned is made still narrower, or only 4 ft. 4 in. on each side of the centre line, as indicated at G, Fig. 978. The general construction of the cross girders here is similar to that already described, but the thickness of plating in the flanges is less.

On the bed line of the dock are short longitudinal girders H H, Figs. 974 to 976, fitting in

978.



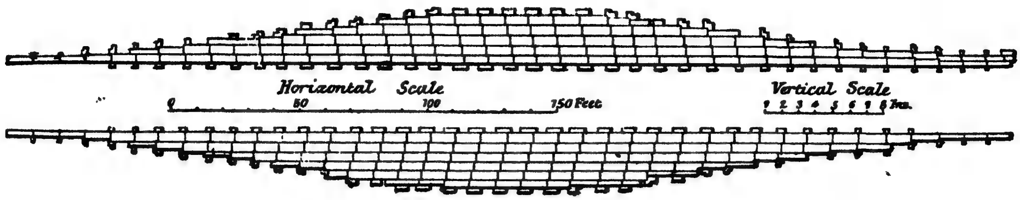
between the cross girders. These girders materially stiffen the cross girders at the part where the load of the ship has to be supported. They also equalize to some extent any unequal loading that may occur, although, being discontinuous, they do not possess any great longitudinal strength. They have web plates 2 ft. $4\frac{1}{2}$ in. deep × $\frac{3}{8}$ in. thick, united by $3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{7}{16}$ in. L irons to a top flange 16 in. wide × $\frac{1}{2}$ in. thick, and to the flooring plates D at the bottom. They are also stiffened with two vertical 6 in. × 3 in. × $\frac{3}{8}$ in. T irons, one on each side. On the top flange of each cross girder at either end is a gusset K, Figs. 974, 975, and 978, 8 ft. high × 3 ft. 8 in. broad at the bottom, formed of a $\frac{5}{16}$-in. plate stiffened at the outside edge with an L iron 3 in. × 3 in. × $\frac{3}{8}$ in., and round the back with an L iron $3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{7}{16}$ in., riveted through to the frame inside the main girder M. This gusset stiffens and strengthens the connection of the cross to the main girders. The ends of the cross girders are also connected to the main girders by a continuous longitudinal L iron, riveted to the webs of the main girders and to the top flange of each cross girder where the L iron crosses it. The vertical L irons at the ends of the cross-girder webs are also riveted through the main-girder webs to the frames inside the latter, Fig. 974. The end plates in the bottom flanges of the cross girders lap over, and are riveted on the top of the uppermost plate in the bottom flange of the main girder, this plate being made to project beyond the others for the purpose. The main girders are stiffened with a transverse frame on the centre line of each cross girder.

The main girder web plates MM, Figs. 974, 975, 978, are 15 ft. long × $\frac{3}{8}$ in. thick, standing vertically, and have a width of 2 ft. $10\frac{1}{2}$ in., and 2 ft. $6\frac{1}{2}$ in. alternately; their vertical joints are lap joints, and not butted according to the usual custom. The rivets used in the laps are $\frac{3}{4}$ in. diameter, and 3 in. pitch. In the four air compartments in each girder, extending from the centre to 120 ft. towards each end, the web plates are stiffened with vertical bulb L irons 5 in. × $3\frac{1}{2}$ in. × $\frac{5}{16}$ in., weighing 10 lb. a foot run, placed inside, and stayed across from web to web at intervals by light horizontal T irons. In the other compartments of the girders which are used as water-ballast tanks, the plates are stiffened with horizontal bulb L irons, of the same section as above, placed inside in 5 ft. lengths, and having their abutments at the transverse frames. The reason why the air and ballast chambers are differently stiffened is that the air chambers, when submerged, have a considerably greater pressure to bear than is ever brought upon the ballast chambers, and must consequently be made stronger. The transverse bulkheads across the air and ballast chambers are

stiffened in a similar manner with horizontal bulb L irons. The webs of the main girders are riveted to the flanges by double L irons, 4 in. × 4 in. × ½ in., riveted with 1 in. rivets. The space between these L irons is ¾ in., so as to allow room for the lap of the two ⅜-in. web plates without having their corners thinned; ⅜-in. liners are inserted between the laps, to make up a uniform thickness.

The flanges of the main girders, which are 400 ft. long, are of great width and thickness, to give longitudinal strength to the dock; the arrangement of the plates is shown, Figs. 979, 980.

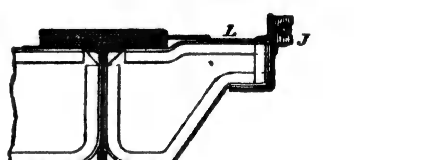
979.

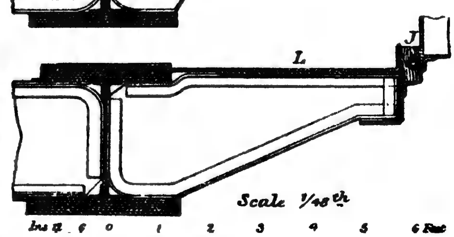


The bottom flange at the centre, Fig. 980, is composed of four layers of ⅝-in. plates, and two layers of ½-inch plates. The width of the uppermost layer, or that next the L irons, is 6 ft. 5½ in., made up of one plate 3 ft. 4 in. wide, and one plate 3 ft. 1½ in. wide. All the other layers are 6 ft. wide, made up of one plate 3 ft. 4 in. wide, and one plate 2 ft. 8 in. wide, the wide and narrow plates being placed alternately on opposite sides, so as to break joint. The extra 5½ in. in the width of the uppermost layer is to form the projecting lip upon which the end plates of the bottom flanges of the cross girders are riveted, Fig. 974. The top flange at the centre, Fig. 979, is composed of five layers of ⅝ in plates, each layer being 6 ft. wide, and arranged in a similar manner to those in the bottom flange. Both top and bottom flanges are reduced at the ends to one plate of ⅝ in. thickness, excepting the top flanges at the gate end, which are reduced to two plates of ⅝ in. thickness. All plates, excepting those at the ends of the layers, are 10 ft. long, and the rivets, which are 1 in. diameter, have a continuous pitch of 4 in., maintained for the whole length of 400 ft. The rivets in the projecting edge of the bottom flange, for connection to the cross girders, are ¾ in. diameter, and 3 in. pitch for the centre 210 ft.; beyond this length the cross-girder flooring is raised, as in Fig. 974, and the riveting, which is not continuous, is done with rivets 1 in. diameter.

The closed end of the dock is formed of a single skin of plates, 15 ft. long, set vertically, with their joints lapped. This plating is supported by six strong vertical gussets, 12 ft. 6 in. high, and 5 ft. broad at the bottom. There is no internal gusset on the centre or keel line of the dock, but a vertical girder is placed outside, so as to leave this part perfectly clear for the stem of a long ship. The plating of the closed end is further stiffened by long horizontal bulb L irons placed outside, and by a horizontal girder at top, also outside, which is 2 ft. wide and forms the gangway across the end of the dock. The closed end forming a girder 15 ft. in depth, adds considerable transverse stiffness to the dock at this part.

981.





982.

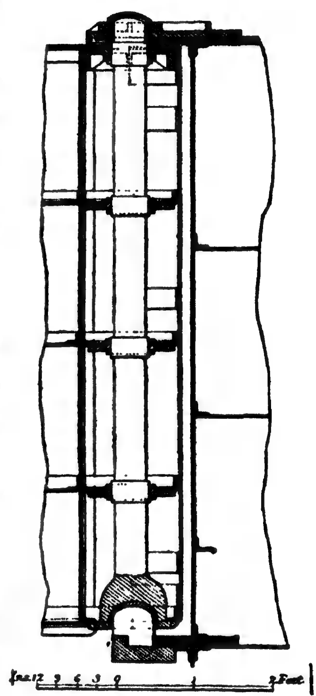
At the open or gate end of the dock, Fig. 978, no such girder as the above could possibly be used, and there were, moreover, many considerations connected with the gates themselves which made it a matter of great importance that the cross girder at this end should possess, both in itself and in its attachments to the main girders, far more than the ordinary strength considered necessary for the other cross girders. It was therefore determined to reduce the depth of the end bulkhead in the main girders, Fig. 975; to make the web of this cross girder, which is 2 ft. 6 in. in depth, continuous between the two outside webs of the main girders; and to make the bottom flange of the cross girder, which at the centre is 36 in. wide by 2⅝ in. thick, continuous right through, and riveted to the outside L iron in the bottom flange of the main girder; finally, to make the top flange of this cross girder, which in the centre is 30 in. wide by 3¾ in. thick, also continuous right through to the outside web of the main girder. This construction is shown in Fig. 974, and the section of the end cross girder in Figs. 981, 982. In the top flange of this end cross girder, the end plates of the lowest layer are also made of such a width as to extend along inside the main girders a distance of 5 ft.; and the whole of this plating being thoroughly secured with double L irons, the end cross girder and the two main girders are thoroughly incorporated together.

The horizontal triangular projection L carrying the gate sill J, Figs. 978, 981 and 982, is made of a ⅝ in. plate, riveted to the projection of one of the plates in the top flange of the end cross girder, and supported by strong plate and L iron gussets placed underneath. Along the edge of

this triangular projection L and on the end bulkheads of the main girders is fixed the timber J, which forms the water-tight seat between the gate and the end of the dock. In this timber, which is secured to the L irons with $\frac{5}{8}$ in. wooden screws and caulked with oakum, is a groove, which is planed out to a diameter of $2\frac{5}{16}$ in. and a depth of $1\frac{1}{16}$ in. In this groove is placed an indiarubber, projecting about $\frac{3}{8}$ in. beyond the face of the timber. The object of having the rubber made with a central hole was, that when it was pressed home flush with the face of the timber it might fill up this hole, and not be frayed by being squeezed and crushed over the edge of the timber. The outward pressure of the rubber is sufficient to prevent the water from passing, while the timber takes almost the whole of the pressure received from the gate, and thus prevents the nature of the rubber from being destroyed.

The gates, one of which is shown in sectional plan in Fig. 978, are 12 ft. 3 in. in depth and about 26 ft. long; they are straight on the inside, but curved on the outside to a radius of 65 ft. $7\frac{1}{2}$ in., and are made with a double skin of $\frac{3}{8}$-in. plates, with their lengths placed horizontally. These plates are lapped at their sides, but butted at their ends. There are five horizontal and three vertical plate diaphragms in each gate, thus dividing it into eight compartments; of these the four upper ones are open for the water to flow in and out, while the four lower ones are permanent air chambers, and when submerged have a displacement just sufficient to balance the weight of the gates, and make them water-borne. The lower compartments were fixed upon as the air chambers in order that when the dock was being worked with a large amount of free board, the gates might still be as nearly as possible floating. In addition to the three vertical plate diaphragms there are at 5 ft. centres, strong vertical plate and L-iron frames, extending from top to bottom; and in addition to these, there are in the air chambers extra plate and L-iron stiffeners, to resist the water pressure when the dock is at the bottom of the lift pit. All rivets in the gate are $\frac{3}{4}$ in. diameter, and 3 in. pitch. At the mitres of the gate are fixed, each between two angle irons, two vertical timbers, which meet when the gates are shut, and complete the water-tight seal.

983.



The hinge of each gate, Fig. 983, consists of a forged wrought-iron gate post, $7\frac{1}{2}$ in. in diameter, which passes through horizontal diaphragms in the semicircular end of the gate, and is fixed in place by cast-iron distance pieces. The top of this gate post works in a gun-metal cap, which fits in a Bessemer steel casting riveted to the plates at the end of the top flange of the main girder, and also firmly secured by a collar let into these plates and run in with zinc. The bottom of the gate post is enlarged and hollowed out to fit over a gun-metal bush, which works on a Bessemer-steel casting forming the pivot; this pivot fits into a semicircular slot in the plates forming the top flange of the end cross girder, and the table or flat part of the casting fits and is riveted in between the underside of this top flange, and a pair of plate and double L-iron brackets which are riveted to the web of the end cross girder. The gates are closed by strong chains attached to eye-plates on the gate, and passed over sheaves to a barrel fixed between the last pair of side gussets; the barrel is worked with a worm wheel by a long vertical shaft from the top of the main girder. The gates are opened by ropes passed over sheaves fixed to the dolphins at the entrance to the lift, and led back to capstans placed on the ends of the lift platform.

The following calculations relating to this important dock are due to Charles Elwin, of London;—

To estimate the Stresses on Flanges of Main Girders, when the Dock is afloat.—The total weight of the dock is 1650 tons, of which about 60 tons is supported by the displacement of the iron and timber beneath the level of the lower flooring of the dock. This amount may therefore at once be dismissed from the calculation, reducing the weight to 1590 tons. There may also be dismissed from the calculation the weights of the crane and gate at the after end, and of the closed end, engines and pumps at the forward end, as these are more or less neutralized by local buoyancy; and as moreover they are not evenly distributed, they would, if taken into account, complicate the calculations without any corresponding advantage in accuracy.

The calculations are based upon the weights of the main and cross girders, and are as follows;—

From centre to 105 ft. from centre	=	4·5 tons a foot run.
„ 105 ft. to 150 ft. „ „	=	3·5 „ „
„ 150 ft. to 200 ft. „ „	=	2·5 „ „

So that the total weight for the calculations is—

	Ft.		Tons.		Tons.
For length from centre to 105 ft. from centre	210	×	4·5	=	945
„ „ 105 ft. to 150 ft. „ „	90	×	3·5	=	315
„ „ 150 ft. to 200 ft. „ „	100	×	2·5	=	250
					1510

In the calculations of displacements no account is taken of that due to the air compartments for engines and the like, these being neutralized by local loads. The displacement above the upper floor levels will therefore be 400 ft. length × 58·8 ft. width, giving 653 tons a foot of draught of

dock, this including the space occupied by the water ballast. The displacement between the lower and upper floor level, also including space occupied by water ballast, varies according to the arrangement of the flooring, and is—

		Ft.		Ft.		Tons a foot run.		Total tons.
From centre to 105 ft. from centre	..	58·8	×	2·5	=	4·08	or	856·8
„ 105 ft. to 150 ft. „ „	..	27·2	×	2·5	=	1·89	or	170·1
„ 150 ft. to 200 ft. „ „	..	19·2	×	2·5	=	1·33	or	133·0
								1159·9

or 1160 tons total displacement between the two floor levels.

The displacement above upper floor level due to the weight of the dock is ascertained by deducting 1160 tons, that below upper floor level, from 1510 tons total weight, leaving 350 tons, which, divided by 400 ft. total length, gives 0·875 ton a foot run; so that the total displacements a foot run, due to weight of dock, will be—

		Below. Tons.		Above. Tons.		Total tons.
From centre to 105 ft. from centre	.. .. ..	4·08	+	0·875	=	4·955
„ 105 ft. to 150 ft. „ „	.. .. ..	1·89	+	0·875	=	2·765
„ 150 ft. to 200 ft. „ „	.. .. ..	1·33	+	0·875	=	2·205

We have then to ascertain the stresses in the main girder flanges, due to the difference between the moments of the weight of the dock, and the moments of the displacements caused by this weight. In this and the subsequent calculations all moments are taken as positive which tend to produce compression in the top flange and tension in the bottom flange, and all opposite moments as negative.

The moments of weight of dock are—

A.

	Tons.		Ft.		Ft.		Tons.		Ft.		Ft.		Tons.		Ft.		Ft.		Foot-tons.
At centre	(4·5	×	105	×	52·5	+	3·5	×	45	×	127·5	+	2·5	×	50	×	175)	=	− 66,762
50 ft. from „	(„	×	55	×	27·5	+	„	×	45	×	77·5	+	„	×	50	×	125)	=	− 34,637
100 ft. „ „	(„	×	5	×	2·5	+	„	×	45	×	27·5	+	(„	×	50	×	75)	=	− 13,762
150 ft. „ „													(„	×	50	×	25)	=	− 3,125

The corresponding moments of displacement of dock;—

A.

	Tons.		Ft.		Ft.		Tons.		Ft.		Ft.		Tons.		Ft.		Ft.		Foot-tons.
At centre	(4·955	×	105	×	52·5	+	2·775	×	45	×	127·5	+	2·205	×	50	×	175)	=	+ 62,472
50 ft. from „	(„	×	55	×	27·5	+	„	×	45	×	77·5	+	„	×	50	×	125)	=	+ 30,919
100 ft. „ „	(„	×	5	×	2·5	+	„	×	45	×	27·5	+	„	×	50	×	75)	=	+ 11,752
150 ft. „ „													(„	×	50	×	25)	=	+ 2,756

The algebraical sum of these moments will give the resultant moments; and the latter divided by 15 ft. the depth of the girder, and by two, the number of main girders, will give the stress on each flange due to the weight of the dock. Thus,—

A.

		Moments due to Weight of Dock. Foot-tons.		Moments due to Displacement. Foot-tons.		Resultant Moments. Foot-tons.		Stress on each Flange. Tons.
At centre	..	− 66,762	+	62,472	=	− 4290	=	− 143
50 ft. from „	..	− 34,637	+	30,919	=	− 3718	=	− 124
100 ft. „ „	..	− 13,762	+	11,752	=	− 2010	=	− 67
150 ft. „ „	..	− 3,125	+	2,756	=	− 369	=	− 12

In the actual calculations of the stresses on the main girder flanges, they were ascertained for sections at 10 ft. apart; but those here given at 50 ft. apart are sufficient to show the system of calculation adopted.

The water ballast extends from 120 ft. from centre of dock to either end of each main girder; its weight a foot run is 2 × 14 ft. × 5·25 ft. × $\frac{1}{35}$ ton a cub. ft. = 4·08 tons, and the downward moments of this weight will be—

B.

		Tons.		Ft.		Ft.		Foot-tons.
At centre	.. ..	4·08	×	80	×	160	=	− 52,224
50 ft. from „	.. ..	„	×	80	×	110	=	− 35,904
100 ft. „ „	.. ..	„	×	80	×	60	=	− 19,584
150 ft. „ „	.. ..	„	×	50	×	25	=	− 5,100

The total displacement caused by this load will equal it in amount, and will be uniformly distributed, or 653 tons ÷ 400 ft. = 1·63 tons a foot run of length and a foot of draught of the dock; and the upward moments of this displacement will be—

B.

		Tons.		Ft.		Ft.		Foot-tons.
At centre	.. ..	1·63	×	200	×	100	=	+ 32,600
50 ft. from „	.. ..	„	×	150	×	75	=	+ 18,338
100 ft. „ „	.. ..	„	×	100	×	50	=	+ 8,150
150 ft. „ „	.. ..	„	×	50	×	25	=	+ 2,038

The algebraical sum of the last two sets of moments will give the resultant moments; and half the latter divided by 15 ft. depth will give the stresses on each flange due to the water ballast;—

B.

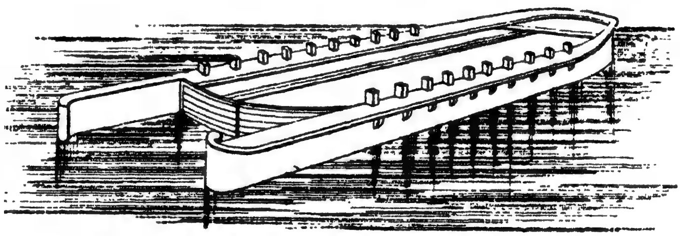
	Moments due to Water Ballast. Foot-tons.		Moments due to Displacement. Foot-tons.		Resultant Moments. Foot-tons.		Stress on each Flange. Tons.
At centre ..	− 52,224	+	32,600	=	− 19,624	=	− 654
50 ft. from „ ..	− 35,904	+	18,388	=	− 17,566	=	− 585
100 ft. „ „ ..	− 19,584	+	8,150	=	− 11,434	=	− 381
150 ft. „ „ ..	− 5,100	+	2,038	=	− 3,062	=	− 102

If an algebraical sum is made of the stresses obtained by calculations A and B, the stresses due to the total dead or permanent load will be obtained;—

	Stresses due to Weight of Dock. Tons.	Stresses due to Water Ballast. Tons.		Resultant Stresses due to Total Permanent Load. Tons.
At centre	− 143	− 654	=	− 797
50 ft. from „	− 124	− 585	=	− 709
100 ft. „ „	− 67	− 381	=	− 448
150 ft. „ „	− 12	− 102	=	− 114

To ascertain the effect of the weight of a perfectly flexible long ship, heavy in the centre but light at the ends, two assumptions are made as to the distribution of the weights.

The weight of the ship is assumed to be proportional to its displacement at each section of its length. This weight is plotted on a diagram, and the weight of each portion is calculated, and the distance is ascertained of its centre of gravity from any point round which moments have to be taken. The ship in this example is taken as 381·9 ft. long × 44·7 ft. beam, and displaces on an even keel, and at an 18 ft. draught, 3944 tons of water, its gross registered tonnage being 3664 tons.



Taking the same four points in the length of the dock as before at which to calculate the stresses, and calculating for each of those points the downward moments of those parts of the ship only which lie beyond that point, the moments due to the weight of the ship are found—

		Foot-tons.
At centre	=	− 125,334
50 ft. from „	=	− 47,880
100 ft. „ „	=	− 10,134
150 ft. „ „	=	− 316

The displacement caused by weight of ship is 3944 tons total, or $\frac{3944}{400} = 9 \cdot 86$ tons a foot run; and the moments of this displacement are;—

	Tons.		Ft.		Ft.		Foot-tons.
At centre	9·86	×	200	×	100	=	+ 197,200
50 ft. from „	„	×	150	×	75	=	+ 110,925
100 ft. „ „	„	×	100	×	50	=	+ 49,300
150 ft. „ „	„	×	50	×	25	=	+ 12,325

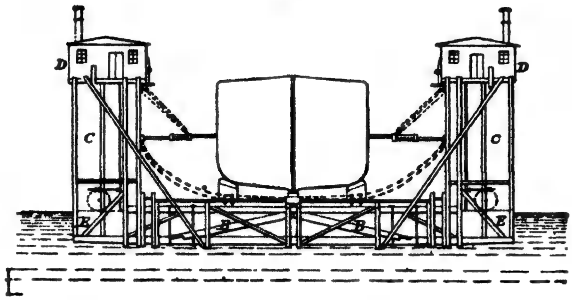
The following algebraical sum of the moments due to the weight of the ship and to the displacement caused by this weight will give the resultant moments due to the ship; and dividing half the latter by 15 ft. depth, as before, will give the stresses on each flange;—

	Moments due to Weight of Ship. Foot-tons.		Moments due to Displacement. Foot-tons.		Resultant Moments. Foot-tons.		Stress on each Flange. Tons.
At centre	− 125,334	+	197,200	=	+ 71,866	=	+ 2396
50 ft. from „	− 47,880	+	110,925	=	+ 63,045	=	+ 2102
100 ft. „ „	− 10,134	+	49,300	=	+ 39,166	=	+ 1300
150 ft. „ „	− 316	+	12,325	=	+ 12,009	=	+ 400

Finally, the following algebraical sum will give the total resultant stresses due to weight of ship and permanent load;—

	Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.		Stress. Tons.
At centre	− 797	+	2396	=	+ 1599
50 ft. from „	− 709	+	2102	=	+ 1393
100 ft. „ „	− 448	+	1306	=	+ 858
150 ft. „ „	− 114	+	400	=	+ 286

985.



The same ship is taken as in the last calculation, but the distribution of its load is assumed to be four-fifths of the total load uniformly distributed over the central two-thirds of the length of the ship, and the remainder uniformly distributed over the ends. This distribution Elwin believes to be generally accepted as approximately correct.

The length of the ship being 354 ft. on the keel, its weight will now be distributed;—

		Tons.
13·37 tons a foot run on 236 ft. in centre	=	3155
6·69 „ „ 59 ft. at each end	=	789
Total weight	=	3944

The moments of the weight of the ship will be;—

	Tons.		Ft.		Ft.		Tons.		Ft.		Ft.		Foot-tons.
At centre ..	(13·37	×	118	×	59	+	6·69	×	59	×	147·5)	=	− 151,302
50 ft. from „ ..	(„	×	68	×	34	+	„	×	59	×	97·5)	=	− 69,396
100 ft. „ „ ..	(„	×	18	×	9	+	„	×	59	×	47·5)	=	− 20,915
150 ft. „ „ ..							(„	×	27	×	13·5)	=	− 2,438

The moments of the displacement are the same as in the last calculation; and the following algebraical sum will give the resultant moments due to the ship, and, dividing by 2 × 15 ft. depth, the stresses on each flange;—

	Moments due [illegible] Foot-tons.		Moments due [illegible] Foot-tons.		Resultant Foot-tons.		Stress [illegible] Flange. Tons.
At centre	− 151,302	+	197,200	=	+ 45,898	=	+ 1,530
50 ft. from „	− 69,396	+	110,925	=	+ 41,529	=	+ 1,384
100 ft. „ „ ..	− 20,915	+	49,300	=	+ 28,385	=	+ 946
150 ft. „ „ ..	− 2,438	+	12,325	=	+ 9,887	=	+ 330

Finally, the following algebraical sum will give the total resultant stresses due to weight of ship and permanent load;—

	Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.		Total Resultant Stress. Tons.
At centre	− 797	+	1530	=	+ 733
50 ft. from „	− 709	+	1384	=	+ 675
100 ft. „ „	− 448	+	946	=	+ 498
150 ft. „ „	− 114	+	330	=	+ 216

To ascertain the effect of a short heavy ship, take for example a vessel 313·3 ft. long × 38 ft. beam, which displaces, on an even keel and at an 18 ft. draught, 2967 tons of water, its gross registered tonnage being 2178 tons. The same two assumptions as to distribution of load are taken as in the last calculation.

The following algebraical sums will give the total resultant stresses due to weight of ship and permanent load on either method;—

First Method.

	Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.		Total Resultant Stress. Tons.
At centre	− 797	+	2308	=	+ 1511
50 ft. from „	− 709	+	1989	=	+ 1280
100 ft. „ „	− 448	+	1151	=	+ 703
150 ft. „ „	− 114	+	309	=	+ 195

Second Method.

At centre	− 797	+	1733	=	+ 936
50 ft. from „	− 709	+	1547	=	+ 838
100 ft. „ „	− 448	+	990	=	+ 542
150 ft. „ „	− 114	+	309	=	+ 195

To ascertain the effect of a long heavy ship, the ship in this example is taken as 420 ft. long × 42·5 ft. beam, and displaces, on an even keel and at an 18 ft. draught, 4400 tons of water, its gross registered tonnage being 3850 tons. The same two assumptions are made as in the previous calculations.

First Method.

	Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.		Total Resultant Stress. Tons.
At centre	− 797	+	1943	=	+ 1146
50 ft. from „	− 709	+	1745	=	+ 1036
100 ft. „ „	− 448	+	1129	=	+ 681
150 ft. „ „	− 114	+	368	=	+ 254

Second Method.

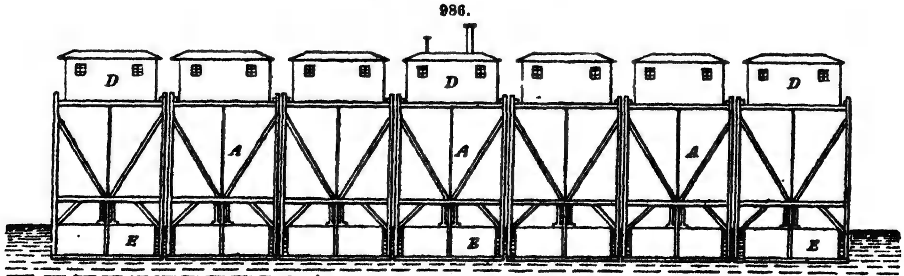
At centre	− 797	+	1041	=	+ 244
50 ft. from „	− 709	+	944	=	+ 235
100 ft. „ „	− 448	+	652	=	+ 204
150 ft. „ „	− 114	+	202	=	+ 88

The above results are combined in Table I.;—

Table I.

Resultant Stresses on Main Girder Flanges.	Long ship, heavy in centre, light at ends.		Short heavy ship.		Long heavy ship.	
	First assumed distribution.	Second assumed distribution.	First assumed distribution.	Second assumed distribution.	First assumed distribution.	Second assumed distribution.
	tons	tons	tons	tons	tons	tons
At centre	+ 1599	+ 733	+ 1511	+ 936	+ 1146	+ 244
50 ft. from „	+ 1393	+ 675	+ 1280	+ 838	+ 1036	+ 235
100 ft. „ „	+ 858	+ 498	+ 703	+ 542	+ 681	+ 204
150 ft. „ „	+ 286	+ 216	+ 195	+ 195	+ 254	+ 88

986.



The effect of the water ballast upon the stresses on the flanges of the main girders is shown by calculation B, p. 445; from which it will be seen that the amount by which the stresses in the last table would be increased, if there were no water in the ballast chambers, is;—At centre, 654 tons; 50 ft. from the centre, 585 tons; 100 ft. from the centre, 381 tons; and 150 ft. from the centre, 102 tons.

If these chambers were left open to the outside water, so that the contained water would be level with that in which the dock was floating, or in other words so that the depth of water in the ballast chambers would equal the draught of the dock, then the reduction of the stresses would be from $\frac{9}{14}$ to $\frac{11}{14}$ of that given above, according to the draught of the dock; but when really most required, with the short ship of small maximum but great proportional load, the relief afforded to the main girder flanges would be least, as the draught of the dock in this instance would be less than in the other cases.

The effect of raising the flooring, is to transfer the centre of gravity of a portion of the displacement, on each side of the centre of the dock, to a point considerably nearer the centre, with a corresponding reduction in the stresses on the main girder flanges.

The following are the actual displacements below the upper floor level exclusive of the side girders, 1 cub. ft. of water weighing $\frac{1}{35}$ ton;—

		Ft. in.		Ft. in.		Ton.		Tons a Foot Run.		Total Tons.
Centre to 105 ft. from centre ..	=	48 2	×	2 6	×	$\frac{1}{35}$	=	3·34	or	351
105 ft. to 150 ft. " ..	=	16 8	×	"	×	"	=	1·157	"	52
150 ft. to 200 ft. " ..	=	8 8	×	"	×	"	=	0·60	"	30
Total displacement on each side of centre										433

The distance of the centre of gravity of this displacement from the centre of the dock is 69·99 ft., say 70 ft., or 30 ft. less than that for uniform displacement. The reduction in the stresses on the flanges is given in Table II.

TABLE II.

	Stress on each Flange with uniform Displacement.	Stress with Displacement as modified by raising the Flooring.	Reduction effected by raising the Flooring.
	tons	tons	tons
At centre	1443	1010	433
50 ft. from "	812	428	384
100 " " "	361	124	237
150 " " "	90	25	65

When the dock is on the lift, the maximum stresses on the main girder flanges occur, when the dock and ship have been raised by the hydraulic lift till the dock has 12 in. freeboard, inasmuch as, previous to this, the ship is to a greater extent water-borne, and the weight on the hydraulic lift is less; and, subsequent to this, the weight is more or less supported, by the buoyancy caused by pumping out the water from the interior of the dock, which operation again relieves the pressure on the hydraulic lift. When the dock is in this position with 12 in. freeboard, almost all the iron, except that in the top flanges of the main girders, is submerged; the weights of the dock will, therefore, be taken one-eighth less than in the calculations for the dock when afloat, and will be from centre to 105 ft. from centre 3·94 tons a foot run; from 105 ft. to 150 ft. from centre, 3·06 tons a foot run; from 150 ft. to 200 ft. from centre, 2·19 tons a foot run.

So that the total weight for the calculations is;—

	Ft.		Tons.		Tons.
For length from centre to 105 ft. from centre ..	210	×	3·94	=	827·5
" " 105 ft. to 150 ft. " ..	90	×	3·06	=	275·5
" " 150 ft. to 200 ft. " ..	100	×	2·19	=	219·0
Total					1322·0

For the unbalanced weight at the ends, a total extra load of 80 tons is assumed, or 40 tons at each end, 200 ft. from centre. Thus the total weight of the dock will be 1322 + 80 = 1402 tons.

The water ballast, being level with the outside water, does not affect the calculation. The ship although already partly raised, is still drawing about 10 ft. 6 in. of water, and its displacement reduces the amount of its weight that has to be supported on the hydraulic lift. The air chambers in the main girders have a displacement of 2 × 14 ft. × 5·25 ft. × $\frac{1}{35}$ ton a cub. ft. = 4·08 tons a foot run, which for a length of 240 ft. gives 979 tons as the amount to which the air chambers relieve the hydraulic lift. The dock when in the lift is always placed with its centre 2 ft. 6 in. farther forward than the centre of the lift; and all the stresses given are for the after end of the dock.

First, to ascertain the stresses on the main girder flanges, due to the difference between the moments of the weight of the dock, and the moments of the displacement of the air chambers, and of the support given by the hydraulic presses.

		Tons.
Downward pressure.—Weight of dock	=	1402
Upward pressures.—Buoyancy of air chambers	=	979
Pressure on rams, 16 pair, at 26·44 tons	=	423
Total	=	1402

Moments of Weight of Dock.

	Tons.	Ft.	Ft.	Tons.	Ft.	Ft.	Tons.	Ft.	Ft.	Tons.	Ft.	Foot-tons.
At centre	(3·94 ×	105 ×	52·5 +	3·06 ×	45 ×	127·5 +	2·19 ×	50 ×	175 +	40 ×	200) =	− 66,439
50 ft. from „	(„ ×	55 ×	27·5 +	„ ×	45 ×	77·5 +	„ ×	50 ×	125 +	„ ×	150) =	− 36,319
100 ft. „ „	(„ ×	5 ×	2·5 +	„ ×	45 ×	27·5 +	„ ×	50 ×	75 +	„ ×	100) =	− 16,049
150 ft. „ „	(——						„ ×	50 ×	25 +	„ ×	50) =	− 4,737

Moments of Displacement of Air Chambers.

	Tons.		Ft.		Ft.		Foot-tons.
At centre	4·08	×	120	×	60	=	+ 29,376
50 ft. from „	„	×	70	×	35	=	+ 9,926
100 ft. „ „	„	×	20	×	10	=	+ 816
150 ft. „ „	no displacement beyond 120 ft.						

The moments of the pressure of the rams, of which there are eight pairs aft of the centre of the dock, spaced 20 ft. apart, are as follows;—

	Tons.		No.		Ft.		Foot-tons.
At centre	26·44	×	8	×	82·5	=	+ 17,450
50 ft. from „	„	×	6	×	52·5	=	+ 8,329
100 ft. „ „	„	×	3	×	32·5	=	+ 2,578
153 ft. „ „	„	×	1	×	2·5	=	+ 66

The following algebraical sum of these moments will give the resultant moments due to the dead or permanent load, whence the stresses on each flange are obtained by dividing by 2 × 15 ft. depth;—

		Moments of Weight of Dock. Foot-tons.		Moments of Displacement of Air Chambers. Foot-tons.		Moments of Pressure on Rams. Foot-tons.			Resultant Moments. Foot-tons.			Stress on each Flange. Tons.
At centre	−	66,439	+	29,376	+	17,450	=	−	19,613	=	−	654
50 ft. from „	−	36,319	+	9,996	+	8,329	=	−	17,994	=	−	600
100 ft. „ „	−	16,049	+	816	+	2,578	=	−	12,655	=	−	422
150 ft. „ „	−	4,737	+	000	+	66	=	−	4,671	=	−	156

To ascertain the effect of the weight of a perfectly flexible long ship, heavy in the centre but light at the ends, the weights are plotted and the weight of each portion is calculated, and the distance is ascertained of its centre of gravity from any point round which moments have to be taken. The displacements at 10 ft. 6 in. draught are treated in a similar manner. The ship in this example is the same as at p. 446, its total displacement or weight being 3944 tons, and its displacement at 10 ft. 6 in. draught being 1704 tons; so that the load on the rams is 3944 tons − 1704 tons = 2240 tons, which on sixteen pairs of rams gives 140 tons a pair due to excess weight of ship.

Moments of Hydraulic Presses.

	Tons.		No.		Ft.		Foot-tons.
At centre	140	×	8	×	82·5	=	+ 92,400
50 ft. from „	„	×	6	×	52·5	=	+ 44,100
100 ft. „ „	„	×	3	×	32·5	=	+ 13,650
150 ft. „ „	„	×	1	×	2·5	=	+ 350

The moments of the total weight of the ship are the same as at p. 446, and as the moments of the displacements of the ship at 10 ft. 6 in. draught are ascertained in the same manner, it will not be necessary to give in detail the process by which the calculations are obtained, and they will be merely inserted in the algebraical sum of upward and downward moments. The same two assumptions are made with regard to the distribution of the load.

Taking the first, the following algebraical sum will give the resultant moments due to the ship;—

		Moments due to Weight of Ship. Foot-tons.		Moments due to Displacement of Ship. Foot-tons.		Moments due to Hydraulic Presses. Foot-tons.			Resultant Moments. Foot-tons.			Stress on each Flange. Tons.
At centre	−	125,334	+	51,962	+	92,400	=	+	19,028	=	+	634
50 ft. from „	−	47,880	+	18,635	+	44,100	=	+	14,855	=	+	495
100 ft. „ „	−	10,134	+	3,619	+	13,650	=	+	7,135	=	+	238
150 ft. „ „	−	316	+	105	+	350	=	+	139	=	+	5

And the following algebraical sum will give the total resultant stresses due to weight of ship and permanent load;—

		Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.			Total Resultant Stress. Tons.
At centre	−	654	+	634	=	−	20
50 ft. from „	−	600	+	495	=	−	105
100 ft. „ „	−	422	+	238	=	−	184
150 ft. „ „	−	156	+	5	=	−	151

On the second assumption, the following algebraical sum will give the resultant moments due to the ship;—

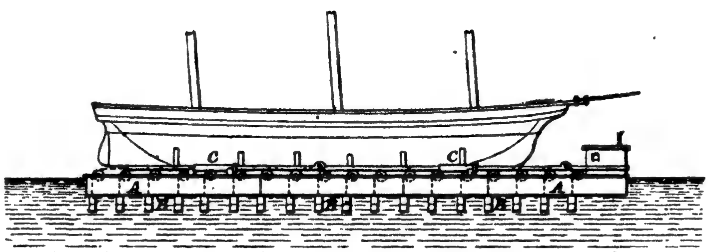
		Moments due to Weight of Ship. Foot-tons.		Moments due to Displacement of Ship. Foot-tons.		Moments due to Hydraulic Presses. Foot-tons.			Resultant Moments. Foot-tons.			Stress on each Flange. Tons.
At centre	−	151,302	+	51,962	+	92,400	=	−	6940	=	−	231
50 ft. from „	−	69,396	+	18,635	+	44,100	=	−	6661	=	−	222
100 ft. „ „	−	20,915	+	3,619	+	13,650	=	−	3646	=	−	122
150 ft. „ „	−	2,438	+	105	+	350	=	−	2003	=	−	66

Finally, the following algebraical sum will give the total resultant stresses due to weight of ship and permanent load;—

		Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.			Total Resultant Stress. Tons.
At centre	−	654	−	231	=	−	885
50 ft. from „	−	600	−	222	=	−	822
100 ft. „ „	−	422	−	122	=	−	544
150 ft. „ „	−	156	−	66	=	−	222

To ascertain the effect of a short heavy ship when the dock is in the lift.—The ship is the same as at pp. 447, 448, its total displacement or weight 2967 tons, and its displacement at 10 ft. 6 in. draught being 1276 tons; so that the load on the rams is 2967 tons − 1276 tons = 1691 tons, which on sixteen pairs of rams gives 105·69 tons each pair due to excess weight of ship.

987.



The following will give the total resultant stresses due to weights of ship and permanent load on the first assumption;—

		Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.			Total Resultant Stress. Tons.
At centre	−	654	+	763	=	+	109
50 ft. from „	−	600	+	613	=	+	13
100 ft. „ „	−	422	+	286	=	×	136
150 ft. „ „	−	156	+	9	=	−	147

And the total resultant stresses due to weight of ship and permanent load on the second assumption;—

		Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.			Total Resultant Stress. Tons.
At centre	−	654	+	188	=	−	466
50 ft. from „	−	600	+	171	=	−	429
100 ft. „ „	−	422	+	125	=	−	297
150 ft. „ „	−	156	+	9	=	−	147

To ascertain the effect of a long heavy ship when on the lift.—The ship is the same as at p. 448, its total displacement or weight being 4400 tons, and its displacement at 10 ft. 6 in. draught being 1900 tons; so that the load on the rams is 4400 tons − 1900 tons = 2500 tons, which on sixteen pairs of rams gives 156·25 tons a pair due to excess weight of ship.

The total resultant stresses due to weights of ship and permanent load on the first assumption are;—

		Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.			Total Resultant Stress. Tons.
At centre	−	654	+	235	=	−	419
50 ft. from „	−	600	+	169	=	−	431
100 ft. „ „	−	422	+	48	=	−	374
150 ft. „ „	−	156	−	50	=	−	206

And—

	Component Stress. Permanent Load. Tons.		Component Stress. Ship. Tons.		Total Resultant Stress. Tons.
At centre	− 654	−	666	=	− 1320
50 ft. from „	− 600	−	632	=	− 1232
100 ft. „ „	− 422	−	428	=	− 850
150 ft. „ „	− 156	−	215	=	− 371

TABLE III.

Resultant Stresses on Main Girder Flanges.	Long Ship, heavy in centre, light at ends.		Short heavy ship.		Long heavy ship.	
	First assumed Distribution.	Second assumed Distribution.	First assumed Distribution.	Second assumed Distribution.	First assumed Distribution.	Second assumed Distribution.
	tons	tons	tons	tons	tons	tons
At centre	− 20	− 885	+ 109	− 466	− 419	−1320
50 ft. from „	− 105	− 822	+ 13	− 429	− 431	−1232
100 ft. „ „	− 184	− 544	− 136	− 297	− 374	− 850
150 ft. „ „	− 151	− 222	− 147	− 147	− 206	− 371

On comparing this summary of results given in Table III. with that given in Table I., it will be observed that the distributions of weights of ships which give high stresses when the dock is afloat give low stresses when the dock is in the lift, and the reverse; and that the differences between the stresses caused by the weights of the ships, taken upon the two different assumptions, are in all cases very considerable. It was difficult however to determine the exact, or even the approximate, distribution in which the weight of the ship would be conveyed to the dock, involving as the question does, the relative stiffness of the two as longitudinal girders. It was therefore determined to take the highest stresses as the basis upon which to proportion the material in the flanges: allowing a high unit-stress of 8 tons tension, and 7 tons compression, for the parts of the flanges between the centre, and 120 ft. from the centre, for which parts the calculations give stresses which are to a certain extent hypothetical, in consequence of the perfect flexibility assumed for the ship; and allowing a low unit-stress of 5 tons tension, and 4 tons compression, for the parts towards the ends, for which the calculated stresses approximate more closely to the actual conditions.

To ascertain the stresses on the flanges of the cross girders, fifteen different cases are assumed, of which six are for the dock when afloat, and nine when on the hydraulic lift.

Those for the dock when afloat, take each of the three ships considered in the previous calculations, with distribution of load according to their displacements at an 18 ft. draught;—

With four-fifths of the total load uniformly distributed over the central two-thirds of the length of the ship, and the remainder uniformly distributed over the ends.

With the load uniform for the whole length of the ship; including the case of the keel blocks being removed from one or more of the cross girders, when the heaviest ship is in the dock.

The calculations for the dock when on the hydraulic lift, take the heaviest load brought upon any cross girder by either of the three ships, with distributions of load according to their displacements at an 18 ft. draught, deducting their displacements at 10 ft. 6 in. draught.

With four-fifths of the total load, uniformly distributed over the central two-thirds of the length of the ship, and the remainder uniformly distributed over the ends, deducting the displacement at 10 ft. 6 in. draught.

With their excess weight uniform for the whole length of the ship.

And with their excess weight concentrated, and uniformly distributed on those girders immediately over the hydraulic lift.

In all cases the stresses are calculated at sections taken 4 ft. apart along the girder, the unit-stresses adopted being about $5\frac{1}{4}$ tons tension, and $4\frac{1}{4}$ tons compression, as a maximum.

To show the manner in which the calculations for these girders were worked out, two examples are here given;—

When the dock is afloat, and has on it a long heavy ship weighing 4400 tons, and its distribution of load is assumed to be proportional to its displacement, the centre cross girder in the dock has to support 82·85 tons of the weight of the ship; the total displacement of the dock at this part, under these circumstances, is 87·925 tons a bay, or length of 5 ft. distance between the cross girders. The weight of the cross girder and flooring is 9·2 tons a bay, and the distribution of loads and supports is;—

Load of Ship concentrated at Centre of Cross Girder.	Weight of Cross Girder and Flooring a Bay, evenly distributed over Length of Girder of 48 ft.	Total Displacement a Bay, evenly distributed over Displacement width of 58·8 ft.	Resultant Pressure supported by Main Girders.
tons	tons	tons	tons
− 82·85	− 9·2	+ 87·925	+ 4·125

And the moments at the centre of the cross girder are—

$$\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Foot-tons.}}{}$$

$$\left(\frac{87\cdot925}{2}\times\frac{58\cdot8}{4}\right)+\left(\frac{4\cdot125}{2}\times 26\cdot75\right)-\left(\frac{9\cdot2}{2}\times\frac{48}{4}\right)=+646$$

which, divided by 2·6 ft., the theoretic depth of the girder, gives a stress on the flanges of + 248·5 tons.

When the dock is afloat, and has on it the short heavy ship weighing 2967 tons, and its distribution of load is assumed to be proportional to its displacement, the cross girder at 100 ft. from the centre of the dock has to support 38 tons of the weight of the ship; the total displacement of the dock at this part, under these circumstances, is 70 tons a bay, or length of 5 ft. between the cross girders. The weight of the cross girder and flooring is 9·2 tons a bay, and the distribution of loads and supports is—

Load of Ship concentrated at Centre of Cross Girder.	Weight of Cross Girder and Flooring a Bay, evenly distributed over Length of Girder of 48 ft.	Total Displacement a Bay, evenly distributed over Displacement width of 58·8 ft.	Resultant Pressure supported by Main Girders.
tons − 38	tons − 9·2	tons + 70	tons − 22·8

And the moments at the centre of the cross girder are—

$$\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Tons.}}{}\quad\overset{\text{Ft.}}{}\quad\overset{\text{Foot-tons.}}{}$$

$$\left(\frac{70}{2}\times\frac{58\cdot8}{4}\right)-\left(\frac{22\cdot8}{2}\times 26\cdot75\right)-\left(\frac{9\cdot2}{2}\times\frac{48}{4}\right)=+153$$

which, divided by 2·6 ft., the theoretic depth of the girder, gives a stress on the flanges of + 59 tons.

When the pressure in the fourth column of those two tables is positive or upward, it shows that the displacement at this part of the dock is less than the load, and that there is therefore transferred to it, by means of the main girders, some of the excess displacement from other parts; and in the same way, when the pressure in this column is negative, it shows that the displacement at this part is in excess of the load, the surplus being conveyed away from this part to other parts. The weights of the main girders, and of the water ballast, do not require to be taken into account separately, as they combine with the ordinary vertical pressures on the main girders; and for the cross girder calculations it is not necessary to know, in what proportions the vertical pressure on the main girders is influenced by the weight of the ship, or by the weight of the main girders and ballast.

Towards the ends of the dock, where part of the flooring is raised, the displacement is not uniform for the whole length of the cross girder, and the moments of these displacements vary accordingly.

When the dock is on the hydraulic lift and has a ship on it, the excess weight over the displacement of the ship is taken as a central load on the cross girder; and the calculations have therefore no peculiarity of any interest.

The stresses for the flanges of the special cross girder at gate end of dock, are calculated assuming that no part of the water pressure on the gates is borne by the sill, but that the whole of it is supported at the mitres and gate posts, thus producing an end thrust proportionate to the total water pressure.

To the stresses caused by the thrust of the gates have to be added those caused by the displacement of the triangular projection L, Figs. 978 and 981, and of a half bay of the dock at this part; as in no case would any portion of the weight of the ship be supported on this end cross girder. The weight of the girder with the triangular projection and half bay of flooring is 16 tons; and the distribution of loads and supports affecting it, when the dock is afloat with a 4400-ton ship, are—

Load of Ship.	Weight of Cross Girder evenly distributed over Length of Girder of 48 ft.	Displacements.				Resultant Pressure supported by Main Girders.
		Below Level of Upper Floor, Half End Bay	Above Level of Upper Floor.		Total Displacement affecting Cross Girder.	
			Half End Bay.	Triangular Projection.		
tons 0·00	tons − 16	tons + 3·32	tons + 33·76	tons + 38·25	tons + 75·33	tons − 59·33

and the moments of these loads and displacements being calculated, it is found that they cause tensile and compressive stresses, respectively, on the top and bottom flanges of this cross girder, varying from 167 tons at centre, to 29 tons at points 24 ft. from centre. The depth of water pressing against the gates, when the dock has on it a ship weighing 4400 tons, is about 8·5 ft., the total draught of dock being about 11 ft.; so that the total pressure acting in a direction parallel to the centre line of the dock is 48 ft. × 8·5 ft. × 4·25 ft. × $\frac{1}{36}$ ton a cub. ft. = 48·17 tons, say 50 tons. Considering the whole of this pressure as supported at the mitres and the gate posts, the thrust at right angles to the centre line of the dock will be equal to ½ of this amount, multiplied by half

the distance between the gate posts, and divided by the rise to the apex of the triangle, or $\frac{12 \cdot 5 \text{ tons} \times 311 \text{ in.}}{67 \text{ in.}} = 58$ tons. The centre of effort of this thrust lies in the same horizontal plane as the centre of pressure of the water, or 5·4 ft. above the bottom flange of the cross girder, or 2·8 ft. above the top flange; and the resulting stresses will therefore be $\frac{58 \text{ tons} \times 5 \cdot 4 \text{ ft.}}{2 \cdot 6 \text{ ft.}} = 120$ tons tension on the top flange, and $\frac{58 \text{ tons} \times 2 \cdot 8 \text{ ft.}}{2 \cdot 6 \text{ ft.}} = 62$ tons compression on the bottom flange. These stresses if added to the stresses caused by the displacements, will give the total stresses on the top and bottom flanges of the end cross girder.

	Stresses due to Displacements. Tons.	Stresses due to Thrust of Gates. Tons.	Total Stresses. Tons.
Top flange at centre	167	120	287 tension.
Bottom flange at centre	167	62	229 compression.
Top flange 24 ft. from centre	29	120	149 tension.
Bottom flange 24 ft. from centre	29	62	91 compression.

But when raising or lowering a ship of the same weight, a case might occur in which the water outside would be nearly up to the level of the top of the gates, when the water inside the dock was 10 ft. below the top; under which circumstances not only would the total pressure against the gates be greater, but its centre of pressure would be higher, and consequently the stresses on the end cross girder would be considerably increased. A calculation was therefore made to ascertain what would be the amount of the thrust under the worst possible circumstances, namely, when the water outside the dock is level with the top of the gates, and the water inside is only up to a level a little above the top of the cross girder, or the bottom of the gate, giving say 12 ft. difference between the outside and the inside water levels. In this case the pressure of water would be 48 ft. × 12 ft. × 6 ft. × $\frac{1}{36}$ ton a cub. ft. = 96 tons; and the thrust taken as before would be 111·4 tons, roughly 112 tons. The centre of effort of this thrust would be 7 ft. above the bottom flange of the cross girder; and the resulting stresses would therefore be $\frac{112 \text{ tons} \times 7 \text{ ft.}}{2 \cdot 6 \text{ ft.}} = 301$ tons tension on the top flange, and $\frac{112 \text{ tons} \times 4 \cdot 4 \text{ ft.}}{2 \cdot 6 \text{ ft.}} = 190$ tons compression on the bottom flange. These added to the stresses caused by the displacements, which are practically the same as in the former calculation, will give the total stresses.

	Stresses due to Displacements. Tons.	Stresses due to Thrust of Gates. Tons.	Total Stresses. Tons.
Top flange at centre	167	301	468 tension.
Bottom flange at centre	167	190	357 compression.
Top flange 24 ft. from centre	29	301	330 tension.
Bottom flange 24 ft. from centre	29	190	219 compression.

The fact that the gates do as a matter of course bear upon the sill, and upon the vertical timbers on the ends of the main girders, materially modifies and lessens these stresses; but in the absence of any other specially transverse stiffener to the dock at this end, it is advisable to make the end cross girder sufficiently strong.

In each of the various plans already considered, with the single exception of careening by the aid of another vessel, it has been necessary that there should be some connection with the solid ground; but Floating Docks, properly so-called, dispense with the necessity of any such connection with the land for the purpose of support, as the dependence for support is on the water alone, the only requirements being a sufficient depth of water, and a holding ground to which the apparatus can be anchored.

As early as 1785 a floating dock was constructed at Rotherhithe, Fig. 984. It consisted of a timber vessel, 245 ft. long, 58 ft. wide, and 23 ft. deep on the blocks, having an open end which could be closed by gates. Water being admitted into the vessel to sink it to a sufficient depth, the gates were opened, the ship to be repaired was drawn in, and then the gates being closed and the sluices shut the water was pumped out, leaving the ship in the interior of a true floating dry dock. Mention is made of one vessel, the 'Mercury,' having been docked in this dock with great success. No provision appears to have been made to regulate the descent of the dock, nor to prevent it from sinking too low, and it is to be assumed that the material employed being wood, was in itself sufficient for this purpose. Docks of a similar character have been constructed at various times and places; but in order to ensure stability they have been sunk between guiding piles upon a level bed, and were therefore not true floating docks, that is, docks independent of the land. Such a dock it appears was proposed to be constructed for the port of Havre about 1848.

In 1809, Trevithick and Dickenson designed a floating dock or caisson of wrought iron, with air chambers at the sides for floating the dock when its body was full of water. It was then to be sunk by admitting just as much water into the air chambers, as was required for making it very slightly in excess of the specific gravity of the water; and the ship being brought over it, the caisson was to be raised by ropes, until its top edge was brought just above the surface, and then the water was to be pumped out of the body of the dock, so as to make the caisson rise all round

the ship, leaving the ship accessible for repair. The size of caisson proposed was 220 ft. long, 54 ft. wide inside, and 30 ft. deep, the top being surrounded by a flat rim, 6 ft. wide, to serve as a working platform, and also to strengthen the edge. The record of this idea appears to possess considerable interest, as showing that even so early as 1809, the possibility of constructing a wrought-iron caisson of these large dimensions was contemplated.

The Sectional Floating Dock, invented about 1837 in the United States, Figs. 985 and 986.—The sections A A, from which the dock takes its name, are each composed of a bottom caisson B, on the ends of which are raised frames C C, carrying platforms and houses D D. The frames are made high enough for the greatest depth to which the dock has to be sunk, so that the platforms and houses may at all times be out of water. In the frames are placed air tanks E E, capable of vertical movement within the frames; or rather the frames are capable of movement past the tanks, as the latter remain without much variation in reference to the level of the water that the dock is floating in. The connection between the tanks and the frames is made by means of rack and pinion gearing, worked off shafting which extends along the dock from the engines in the houses on the central section. The same shafting also works, in all the houses, pumps connected with the bottom caissons B. In applying this dock for lifting a vessel, a number of the sections are brought together, and secured to one another by tie-beams; and sluice valves being opened to admit water into the caissons B the dock begins to sink. The gearing connected with the air tanks E is then put to work, so as to allow the tanks to remain at the surface of the water while the dock sinks to the desired depth, at which it is then held suspended by the air tanks. The sluice cocks are then shut, and the vessel is drawn into the dock and secured in a central position by breast shores. The pumps are then all put to work to raise the dock until the vessel takes the keel blocks, when the bilge blocks are hauled in to support her, and the pumping is continued, causing the dock to rise, lifting the vessel with it. In the act of rising the whole is in a state of unstable equilibrium, and would be liable to turn over, were it not for the air tanks, which by means of the gearing are still kept at the water level. By this arrangement, if the dock endeavour to heel over, it is at once restrained by the air tanks, as it cannot change its perpendicular position without drawing those on one side partially into the water, and raising the opposite ones an equal amount out of the water. Thus if due precautions as to bulkheads be taken in the construction of the dock, to prevent an excessive force from being applied to turn the dock over, the side air tanks are sufficient not merely for determining the point to which the dock shall sink, but also for giving it stability both in rising and in sinking. These sectional docks have been connected with a system of railways, so that a vessel might be run off the dock on to the rails and be repaired there, while the dock was used to lift another vessel.

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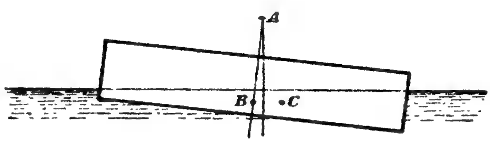

The Balance Dock, or Box Dock, introduced in the United States, consists of a pontoon bottom with two side walls. The pontoon possesses sufficient displacement to carry the whole weight of the dock and of any ordinary vessel that has to be raised. The side walls are hollow and of considerable width, serving the same purpose as the air tanks in the sectional dock, namely, to prevent the dock from sinking. Port holes are made in these walls to assist ventilation, and the walls afford the means of shoring up the ship by breast shores as in a stone dock; on the top are the engine-house and pumps, and the working platform. For lifting the heaviest vessel that could be taken inside the dock, gates have been fitted at the ends of the dock, so that it might float with the surface of the pontoon below the water, and thus acquire an additional amount of buoyant power according to the depth of immersion.

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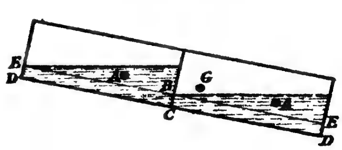

In 1859 F. J. Bramwell designed a plan of floating lift, which combined the principles of the American hydraulic lift and of the floating dock. It consisted, Fig. 987, of two parallel floating pontoons A, carrying between them a framing B, on which the ship was to be lifted by chains, pulleys, traction bars, and hydraulic presses C. Two presses were here applied to each traction bar, one at the further end and one half-way, the strains on the traction bars, and their requisite sectional area, being diminished; and the presses were so arranged that they made the lift in two strokes of half the length. The pontoons were arranged to separate into parts, when required for shorter vessels at different places; but when these parts were used combined together for the largest ships, means were provided to ensure the preservation of the full strength of the pontoons as girders.

In considering the principles of a good floating dock, and the defects most important to be guarded against, the first and principal requirement appears to be, that the ship should be supported on as rigid a bottom as when on a building slip, or in a stone dry dock. This condition is not universally recognized, and on the contrary it is urged that if a vessel has assumed a certain

distorted form in the water, this form ought to be retained when out of the water for the purposes of repair; and it is alleged that this can be accomplished by giving the ship an elastic bearing, such as that afforded by the separate portions of the sectional dock, or by the somewhat yielding saucer of the Thames graving dock. The employment of an elastic bearing appears to F. J. Bramwell to be erroneous, because it is based on the assumption, either that the ship having already gone out of shape to a certain extent will not yield further, or that all the parts of a vessel are of equal weight a foot run, so that the elastic bearing will yield to an equal extent at all parts throughout the entire length of the vessel, which is evidently contrary to fact.

The other requirements of a floating dock are stability, ventilation, facility for repair of the dock itself, and a minimum expenditure of power and time in lifting the dock. The materials employed should be arranged in such a manner as to obtain a maximum of strength from a minimum of material; and the design should be one admitting of many repetitions of a few forms, so as to allow of the work being done to a few standard templates, avoiding as far as possible any necessity for welding heats and smith's work.

As regards the question of stability, the difficulty is experienced not when the dock is raised with the surface of its floor fairly above the water, but during the time that it is in the act of raising or lowering a vessel. The stability of the dock when raised is great, as illustrated by Fig. 988, where A represents the centre of gravity of the dock with the vessel, B the centre of buoyancy when the dock is not heeled over, and C the new centre of buoyancy when the dock is heeled over. It will be seen that the new centre C is far outside the perpendicular from A, and that there is therefore a strong tendency for the dock to right itself. But when the dock has been sunk so that the bottom is entirely below the water line, then some contrivance must be resorted to not merely for keeping it from sinking but also from turning over.

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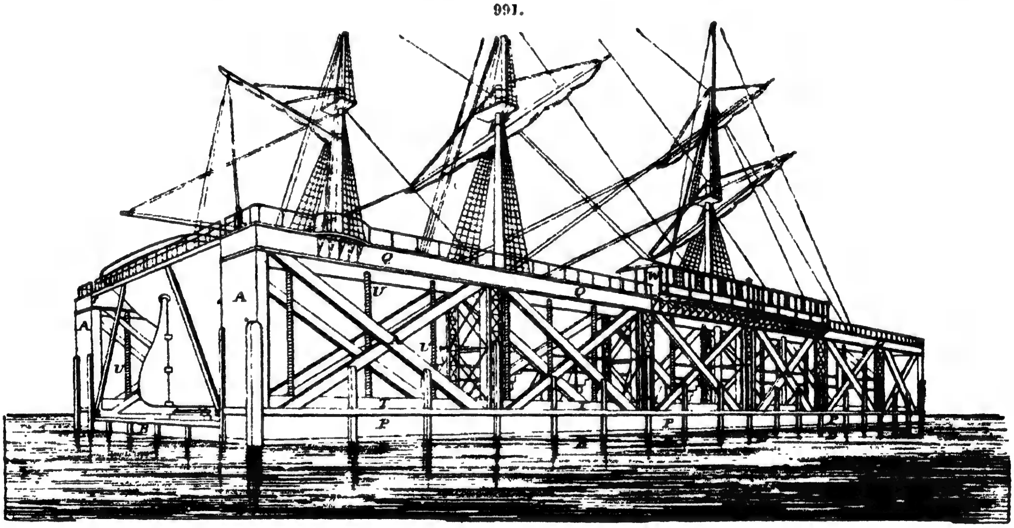

When the vessel in the dock is equally loaded on each side of its centre line, and is placed on the keel blocks perfectly in the centre of the dock, then during the raising of the dock the whole is free from any tendency to turn over, but at the same time is in a state of unstable equilibrium. If the dock heel over a little the causes which would increase its inclination and turn it over are, that the centre of gravity of the ship and dock are no longer over the centre of support, and that the water remaining not yet pumped out shifts its position in the dock.

If a floating dock, made without any longitudinal water-tight bulkheads, were half-full of water, and were to be heeled over sideways, so that the surface of the water should extend as a diagonal from corner to corner, the result would be to shift the centre of gravity of the water to A, Fig. 989, one-third the width of the dock from the lower side. But if the dock has one longitudinal water-tight bulkhead along the centre, Fig. 990, then the same amount of heeling over will cause the surface of the water to assume the shape shown in each compartment, which may be looked on as being in two equal parts, a parallelogram and a triangle. The centre of gravity of the two parallelograms B C, D E, will of course be the same as before the dock was heeled over, while the centres A A of the triangles being one-sixth of the total width from their lower ends, the common centre of gravity G of the two will be at one-twelfth of the width from the centre of the dock, or only half the distance of the centre of gravity in the former case, so that the effective moment tending to turn the dock over is only one-fourth of that which it was without a bulkhead. Similarly if three bulkheads were put in so as to divide the dock into four compartments, the effect of the water in turning the dock over would be reduced to one-sixteenth of what it was when there was no bulkhead; and generally the tendency of the water to turn the dock over, when it is at all inclined, diminishes in the ratio of the squares of the number of chambers into which the dock is divided.

A A, Figs. 991 and 992, which are of a dock constructed by F. J. Bramwell for St. Thomas, West Indies, on these principles, are the main longitudinal girders, and B the separate transverse water-tight pontoons forming the bottom of the dock. These at the ends receive the bottoms of the

main side girders, and as any one pontoon may have either to support the girders or to be partially supported by them, the connection has been made by very strong attachments riveted to the pontoons, and having shanks extending down to the bottom. Cross-plates are placed over the diagonals of the main girders near the junction of the diagonals with the uprights, and on these plates bear strong cotters, so that if one of the pontoons were quite full of water it could be lifted by the others without injury.

The ship is supported in the usual way upon the keel blocks C, which are provided with folding wedges.

The bilges of the ship are supported by hinged bilge-shores N N, which are provided with soft wood caps and wedges to take the immediate bearing against the ship, and are upheld by pauls of two different lengths, so that when the range of the shorter pauls is passed the longer pauls come into play. These pauls take into rack plates, which are supported on transverse timbers. The pressure produced by the bilge-shores is transmitted mainly to the longitudinal water-tight bulkheads J in the pontoons.

The bottom members of each of the main girders A A are formed not only to resist extension, but are provided with sufficient lateral stiffness for resisting compression, by being composed of two parallel double girders P P, connected at the bottom by horizontal struts and diagonal ties.

There are in all twelve floats T, one to each of the two main girders A A; each float is 46 ft. 9 in. long, 11 ft. 3 in. wide, and 5 ft. deep.

The deck on the top of the main girders A A of the dock is widened by brackets for a length of 100 ft. at the centre, and on this part are erected the engine-houses W W, with workshops at the ends.

For the purposes of working, the dock may be considered as divided into four independent sections, for in each of the two engine-houses the engineer has the power of working, independently,

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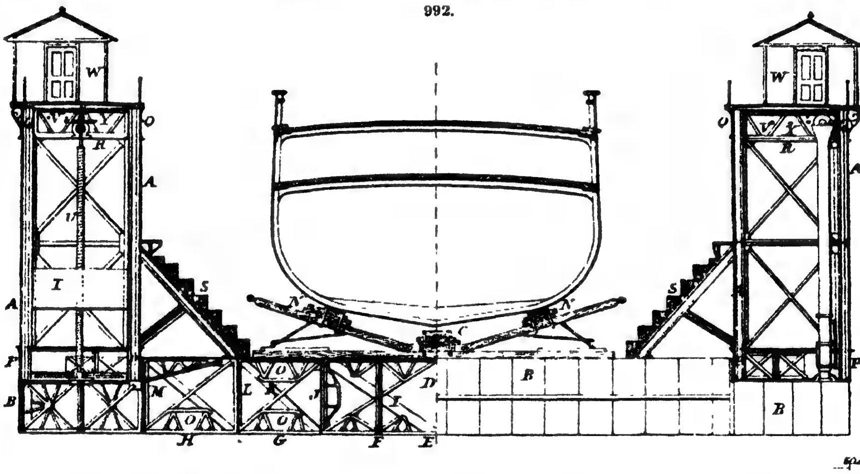

the set of three pumps on the right, and the set on the left; and the same with regard to the floats and the inlet valves. In order to lower the dock for receiving a ship, the inlet valves are all opened to admit the water into the ends of the pontoons as far as the water-tight bulkheads J; the central portion never requires to be filled. While the dock is sinking, the engines working the regulating screws U, are put to work at such a speed as to keep the floats T always one-half immersed in the water. When the dock is sunk to the required depth, the inlet valves are shut, and the ship, which has been moored close to the dock moorings and to the windward of the dock, is hauled in over the keel blocks, and adjusted by means of breast tackles and shores. The pumping engines are then put to work, and the dock is raised until the keel blocks just take their bearing against the vessel; and the bilge-shores being hauled taut so as to secure the vessel thoroughly, the pumping is resumed, and the screw engines are put to work at their slow speed, so that as the dock rises the floats are still maintained just about half immersed.

A reason for discarding the use of slips and lifts would be that they are dependent on the earth for their support. This objection does not apply to the sectional nor to the balance dock, both of which have the advantage of being wholly independent of the land.

In the St. Thomas Dock, although the lower part is composed of six separate pontoons, for facility both of original construction and of subsequent examination and repair, the objection applying to the sectional dock of want of rigidity is got over by the use of the strong side-girders. These are provided with a double set of diagonals, and have their top and bottom members made of such strength as to be capable of resisting a strain tending to depress either the middle or the ends.

As regards stability, the balance dock, mentioned at p. 455, gives nothing to fear so long as the upper surface of the bottom is fairly above the water, because on any attempt at heeling over the rectangular bottom, produces a change in the position of the centre of buoyance, so rapid compared with any slight inclination of the dock, that the tendency to right itself is very strong indeed. In Fig. 993, taking A B as the water line, the balance dock is shown fully raised and heeled over;

and the power of restoring an upright position to the dock, under these circumstances, has already been fully investigated in reference to Fig. 988. But when the dock, while in the act of being raised or lowered, has its floor wholly immersed, as shown by the water line C D, then the tendency to restore equilibrium is not so great, as the effect of the whole triangle E F G is diminished by that of the interior figure H I K L. Moreover, there is at that time within the dock a large amount of water, the centre of gravity of which is, of course, shifted by the heeling over; and the effect of this is most serious, unless a sufficient number of bulkheads be provided to subdivide it into small sections. From whatever cause the stability of a balance dock may have been disturbed, the effect of its sides to restore equilibrium, can be increased only in proportion to the amount of heeling over, and can never be caused to exert any effect in excess of this. If therefore a balance dock has once heeled over, it cannot be righted by its side, so long as the force which caused the heeling over is continued.

With the side floats, however, in the St. Thomas Dock the case is different, as the position of the floats in reference to the dock can be controlled as desired; and in the case of any heeling over an extra immersion can immediately be given to the floats on the low side, while those on the high side can at the same time be raised more out of the water. By this means, when the heeling over is only slight, and the tendency to heel over further is also slight, the floats can be made to exert as great a counteracting power as the walls of the balance dock would have when the heeling over was great, and therefore the tendency to go further also proportionately increased.

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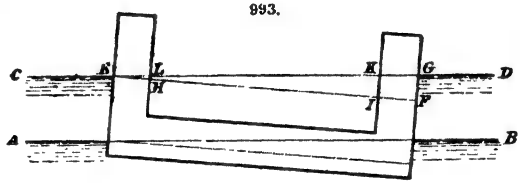

When a dock is connected with a tidal harbour, river, or other water-way, the surface level of which is liable to vary considerably, as with Excavated Docks, already treated at some length at p. 1234 of this Dictionary, the passage by which vessels gain access is provided with massive water-tight gates, constructed so that when closed the water is impounded in the dock, and maintained at a fixed level, notwithstanding the fluctuations of the outer water-way. To receive and support the gates, the passage is constructed with side walls, and a floor or sill *m*, Figs. 994 and 995, the latter usually having the form of an inverted arch. In each side wall, recesses *c* are formed the full depth of the walls, and sufficiently large to allow the gates, when open, to stand back in them clear of the fairway of the passage. The area of the floor traversed by the gates in opening, and termed the gate platform *c*, is usually made level and somewhat below the lowest level of the sill; the step from the sill to the platform, termed the clapping sill *l*, has a vertical face, and is shaped horizontally to form a water-tight junction with the gates when shut. Square quoins *a*, forming the ends of the recesses nearest the dock, are solely for the purpose of protecting the gates, and should be of great strength to withstand the heavy blows to which they are subjected from passing vessels. The ends of the recesses farthest from the dock are the supports for the gates, and require to be made of suitable form and strength; they are termed hollow quoins *k*, and are generally constructed of massive blocks of granite or other hard stone, backed by counterforts of sufficient size and weight to withstand the thrust of the gates; the most common form of hollow quoins is that which presents in plan an outline more or less similar to an ogee moulding. A modification of this form in use at the Liverpool Docks, is shown in Fig. 996, with dimensions for gates of 60 ft. span. These hollow quoins are set with the axes of the curved face strictly vertical, so that they form hollow curves extending the full depth of the wall to the level of the platform on either side of the passage, the hollow face of the bottom blocks forming the terminals of the clapping sills. The gates consist of two exactly similar water-tight doors, and the hinge or heel-post *n* of each gate is vertical and rounded, so as to correspond with the hollow quoins, the round of the heel-post fitting into the hollow of the quoins, and forming, together, the hinge about which the gate turns and the abutment by which it is supported. When moving, the gate is kept in place at the bottom by a pivot and socket connecting the heel-post with the masonry of the platform, and at the top by an iron strap passing round the upper extremity of the hollow post, securely anchored into the structure of the side walls. Each gate is somewhat longer than half the width of the passage; being similar, they meet in the centre line, and form with each other a more or less obtuse angle, having a convex side towards the dock. The meeting or mitre-post of each gate is attached to the vertical end framing of the gate, so that when the gates are shut the meeting face extends the entire depth, and coincides with the centre line of the passage. The meeting faces of the gates consequently form, when closed, both a water-tight joint and mutual abutment. When the gates are of a large size the weight of the gate is greater than can be allowed to remain in the attachment of the hollow post, unless means are adopted to reduce the working weight by the aid of flotation or otherwise, and even then it is necessary to provide against accidents from defective fastenings. A frame or rest is then provided with a travelling wheel or roller, which supports the gate near the mitre-post. The roller rests on an iron way, laid on the gate platform along the path which it traverses; during the pressure of opening or shutting the gates, provision is made by means of wedges, screws, or levers, for adjusting the roller to the gate as the materials wear or circumstances require. As the roller path forms the segment of a circle of which the centre is the axis of the heel-post, it follows that the outer edge of the roller has to travel a greater distance than the inner edge in the same time. To avoid sledging, the rollers should be made conical to a corresponding degree, and the axle on which the roller turns should coincide with a straight line radiating from the axis of the heel-post. The method usually adopted for opening

and shutting large gates is a system of chains, each gate being provided with an opening and closing chain *h*, attached to the back and front respectively, the attachment being as near the sill and mitre-posts, and as low down as can conveniently be arranged.

The details of the opening and shutting of dock gates have been previously dealt with in this Dictionary.

In all rivers and most harbours, water is more or less charged with solid matter and deposits considerable quantities of solid; to scour the gate platform, and prevent such an accumulation of solid as would interfere with the working of gates, a series of small openings on a level with the platform are frequently constructed in the walls of the gate recesses. These openings communicate with culverts *f* which pass under the side walls and the hollow quoins and discharge into the outer water-way. Cloughs or penstocks *g* are placed on the culverts to admit of their being opened or closed as required. The culverts, in addition to the facilities they offer for scouring, afford a means of regulating the level of the water in the dock. Sluice openings provided with paddles are frequently constructed in the gates.

If the surface of the water impounded in the dock is at a higher level than that of the outer water-way, the pressure on the gates due to this difference in level has to be withstood, but conveyed to the side walls by the structure of the gates.

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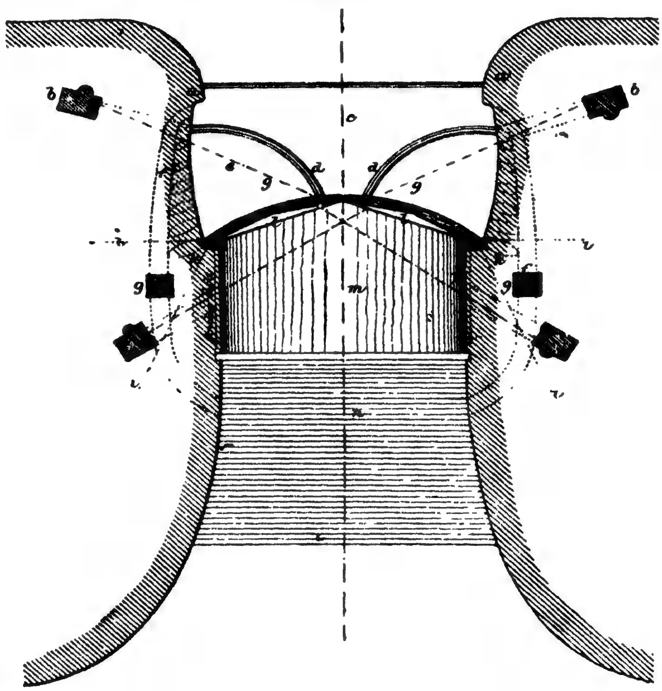

A. F. Blandy, in a paper read before the Institute of Civil Engineers, 1879, points out that if the dock gate be imagined to be divided by a series of cross-sections into a number of vertical strips, each strip being of unit length and the full depth of the gate, then the total pressure of any such strip will be the pressure by unit of length of the gate.

Let p = total pressure on any strip as above, or the pressure by unit of length of gate;
W = weight of water by unit of measure;
D = depth of sill below highest water level; and
d = depth of sill below lowest level of outer water.

Then $p = \frac{W}{2}(D^2 - d^2)$.

The mutual action of the gates on each other is in practice liable to vary; and three cases must be considered;—

1. The gates may be constructed so that, when under pressure, the meeting faces of the mitre-posts bear fair and true against each other, and distribute the mutual reactions uniformly throughout the width of the meeting faces. This is the normal condition of things.

2. Foreign substances, such as chips of wood, may intrude; or the gates may wear, and become a little too short, causing them to nip on the dock, or inner edges of the meeting faces.

3. The gates may be a little too long, in which case they will nip on the outer edges of the meeting faces.

However truly a pair of gates may apparently be fitted, it will be impossible for the engineer to be certain that the meeting faces of the mitre-posts bear on each other at any particular point, or at any specified portions of their surface, and the accident of nipping must be provided for, as it may

throw the line of pressure either to the extreme inner or extreme outer edge of the meeting faces; the effect of nipping will generally be to increase or diminish the normal bending moment at any section by a quantity that may be very readily ascertained from the methods of resolution by the pressures.

In examining the effect of direct compressive stress combined with bending moment such as occur in dock gates, it is necessary to consider the effect on rectangular wooden beams; and the effect on solid rectangular wooden beams supplemented by wrought-iron truss rods, as well as upon wrought-iron girders composed of flanges connected by the centre wheel. Also when the gate is built in divisions corresponding to the voussoirs of an arch, and either depends entirely on the arch form for its power of resistance, in which case no tensile stress can be allowed, or else is assisted by supplementary connecting pieces necessary for this form of gate, to combine the whole into one suitable structure capable of being moved and strained in various directions without dislocation. The wooden gates in use throughout the Liverpool Docks are of this type. It is necessary to reconsider here the effects of stresses on wooden beams. Where the gate depends entirely on the arch form for its stability, the joint between two divisions or voussoirs is the critical point requiring attention. When the gate is built in divisions of small curvatures, with the assistance of supplementary connecting pieces, the joint between two divisions may be still regarded as the critical point to be considered, and it may be assumed that the plane of the joint is made perpendicular to the axis of the gate. Although it might appear that this gate could be regarded as a form of bowstring-girder, the consideration would be inaccurate, as there is nothing to transmit longitudinal stresses from the bow to the string, the transverse bolts being insufficient for that purpose. When the action of a bending moment causes the gate to deflect, the result will be that the transverse bolts, although allowing the voussoirs and connecting pieces to slide on each other longitudinally, will retain them laterally in their relative positions to each other; consequently they will bend through similar angles, and the total moment of resistance will be the sum of the moment of resistance due to the connecting pieces. The direct compressing force will be entirely on the voussoir and may be taken as acting along its centre line, whence the value of the bending moment may be ascertained. Blandy has suggested, in the valuable paper from which we previously quoted, that with gates of this form, connecting pieces should be made of sufficient strength to withstand the whole of the bending moment if necessary. At the same time the voussoirs should be of dimensions determined by the timber to be made use of, and in fixing this limit it should be remembered that the maximum intensity obtained by ordinary methods of analysis corresponds with the maximum intensity on compressed fibres of a beam subject to transverse stress, rather than to intensity on a strut subject to direct stress; for instance, if when designing an ordinary strut, the working intensity is fixed in the ordinary manner at 1000 lb. on the square inch, then in the case of a dock gate of the same materials the limit of intensity might safely be fixed also at 1000 lb. on the square inch notwithstanding that the maximum intensity may be double this.

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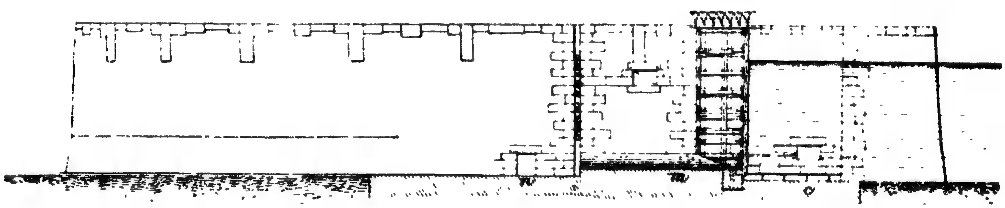

The divisional, or voussoir principle, presents several advantages for dock gates built of timber The timber used need not be of unusual dimensions; the gates can be built in the workshop, and then readily removed piecemeal to their places; they are easily erected, and, if properly constructed, will stand a considerable amount of rough usage, the last being by no means an unimportant qualification. Their construction, however, requires careful supervision and skilled workmanship, which in some places may not be readily obtainable.

As regards the general outline of these gates, Blandy's investigations point to the conclusion that the nearer a gate approaches the form of the true circular arch, the stronger it will be, other things being equal; or, expressing the same thing in another way, with equal strength less materials will be required. In many instances, however, the connecting pieces become cumbersome and of awkward shape when the circular arch is adopted; a difficulty which is to a great extent obviated with the pointed arch, the latter form rendering the gate more compact. It will therefore frequently be preferable to adopt the pointed, instead of the circular arch, even at the sacrifice of a certain amount of timber, the value of the latter being a mere trifle when compared with the total cost of a dock and its fittings.

In designing a gate of the pointed arch form, care must be taken to keep the bending moment within the limits of the moments of resistance, bearing in mind that as the curve of the gate is flattened so are the bending moments increased. The joints should of course be perpendicular to the forces they have to resist. In fitting the gates, since it is impossible to force the heel-post as tight up against the hollow quoin as when the gates are under pressure, it will be best to make them as nearly true as possible, giving a slight preference in favour of nipping at the outer or concave side of the mitre-post, that is, to make the gates apparently very slightly too long. The water pressure and wear at the heel-post will soon bring them to their true form; and in the meantime, in the case of the pointed arch, nipping at the outer side of the mitre-post will tend to lessen the bending moment at the centre of the gate.

With wooden gates such as those referred to, changes of form due to pliability of material may be neglected, if the strength is calculated on the assumption that the gate is subjected to the

extreme condition of nipping at the inner side of the mitre-post. When considering the effect of nipping, it must be remembered that accidental nipping will only occur at isolated points throughout the depth, generally near the surface-level of the water; and the effect will be distributed by means of vertical framing, so as really to amount to but a small fraction of the normal stress. What may be termed structural nipping is of more importance, and may be defined as that caused by the gates being a little too short, or by the faces of the mitre-posts being cut to a wrong angle. But unless great carelessness has occurred in the fittings, and the faces of the mitre-posts are cut away to an extraordinary degree, the changes due to pliability will not increase the stresses, but rather diminish them. The effect of pliability will be to flatten the curve of the gate when under pressure, and by so much to increase the bending moments; but at the same time the meeting face of the mitre-post will have the inner edge drawn back, and the outer edge thrust forward, so that the centre of stress will be transferred from the inner edge to some point nearer the outer edge, and the bending moments will be reduced accordingly, more than counterbalancing the increase due to the flattening of the curve. If, however, it is assumed that the faces of the mitre-posts are so cut away that under any condition of curvature they can only meet at the inner edges, the change of form due to pliability may increase the stresses on the gate. The bending moments throughout the gate when nipping at the inner edge of the mitre-posts, increase from nothing at the heel-post to a maximum at the centre, and again diminish towards the mitre-post. The alteration of curvature under pressure will vary with the bending moments, so that the arc of the gate will assume a somewhat elliptical form. As it is very flat, however, a close approximation may be obtained by assuming that the alteration varies uniformly, and that the new form, instead of being elliptical, is that of a circular arc, such as would be caused by the action of a series of uniform bending moments equally distributed throughout the length, and of which the moment at any point is equal to the mean of the actual bending moments on the gate. To be in excess this may be taken as equal to $\frac{2}{3}$ths of the bending moment at the centre.

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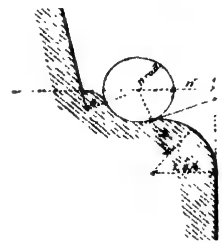


Then, if R = the radius of the arc A O B under pressure, r = the radius of the arc A O B in the normal state, t = the distance from the neutral axis to the convex side of the gate, I = the mean of maximum intensities on the convex side due to the bending moments, and C = the coefficient of elasticity; the new radius of curvature can be found from the equation

$$\frac{R + t}{R\left(1 - \frac{I}{E}\right)} = \frac{r + t}{r}.$$

If L = the length of arc in the normal state, l = the length of arc under pressure, i = the intensity of stress due to direct force;—

$$\text{Then } l = L\left(1 - \frac{i}{E}\right) = L\left(1 - \frac{400}{2{,}000{,}000}\right).$$

The chord and versed sine of the arc A O B under pressure will therefore be those of an arc of which l = the length, R = the radius of curvature.

In the case of wrought-iron gates, there is presented for consideration the effect of direct stress combined with bending moment on a wrought-iron girder composed of flanges connected by a centre web. It may be assumed that the girder is constructed in such a manner that the plane of action of the forces corresponds with the plane of the web, and that the flanges are perpendicular to this plane, so that in the case of a dock gate, it is assumed that the webs are horizontal and the flanges vertical. Practically, on account of the various contingencies to which a gate is subject, it is necessary not to reduce the thickness of the web beyond a certain limit, which usually exceeds that theoretically required to resist shearing stresses. The thickness and consequently the sectional area of the web are questions for the personal experience of the engineer, but the smaller the web the less will be the total section required. In most cases the practical method will be to disregard the web, and to find the dimensions of the flange opposed to the load, or back flange, and of the front flange, throwing in the web as a margin of strength. When the bending moments are small and the stresses comparatively light, as in the upper portion of a gate, it may be desirable to take the web into consideration. This consideration would treat the system as if it was a girder with only one web, whereas a gate has several webs. In computing the strength, a gate may be taken either as a whole, and then proportioned throughout its vertical height, or it may be divided into horizontal layers, and the strength of each layer computed separately. As to the general form of a wrought-iron gate, there can be no doubt that theoretically the most advantageous form is that in which the water pressure produces no bending moment, when the line of centre of gravity of cross-section corresponds with the centre line of the gate, and when the centre lines of both gates form together one continuous arc of a circle extending from centre to centre of the heel-posts and passing through the centre of the meeting faces of the mitre-posts. As regards the rise, F. J. Bramwell has pointed out that the most economical form of gate is that in which a pair of gates when shut form a continuous arc subtending an angle of 133° 56′ at the centre of the circle of which the arc forms a part. The rise of the gates is thus equal to the width from centre to centre of the heel-posts multiplied by 0·32958, in round numbers when the rise equals one-third of the span. It would be useless to attempt to arrive at any general form for the investigation of the variation of stress due to alteration under pressure, as every gate must have its own peculiarities. Practically, if the strength of a gate is calculated on the bases of the extreme cases of nipping at the inner and

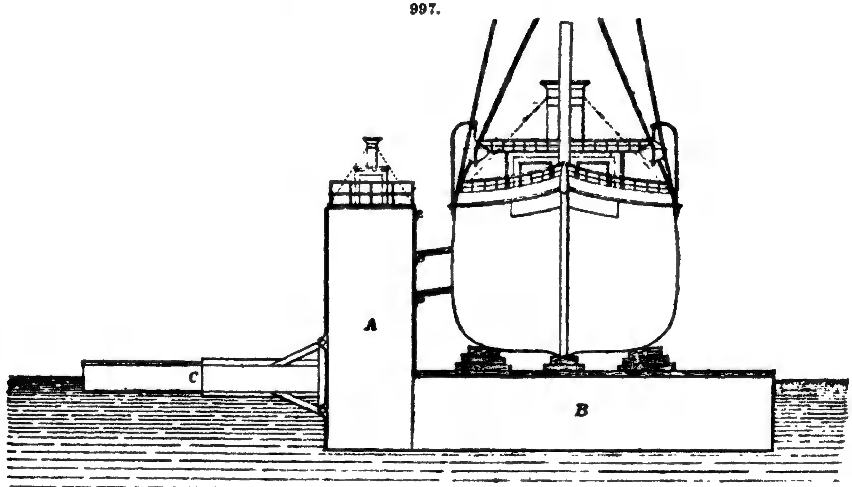
outer edges of the mitre-post, the increased stress due to alteration of form under pressure may be safely ignored.

The most economical is not necessarily the best form of this important part of a dock, and as it is a comparatively small item of the cost, its outlines should be designed with a view to the general convenience and requirements of its construction rather than to the structural economy of the gate itself.

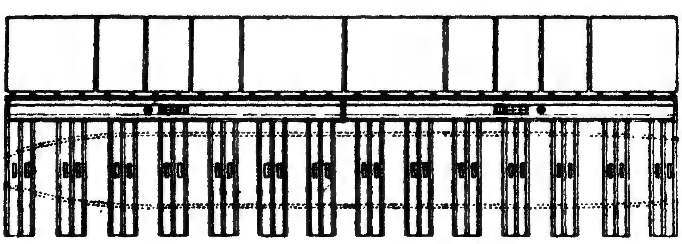
Gates with a large rise and sharply curved backs require deep recesses on the side walls which are not always admissible. A deep bay in the fair line of the side wall when the gate is open is a source of inconvenience to ships passing through, and is to be avoided if practicable. A. F. Blandy is of opinion that for small and medium sized gates up to 60 ft. clear spans, the line of direction of the resultants is the continuous arc passing through the centres of the heel-post and of the meeting faces of the mitre-posts, and having its centre on the centre line of the entrance, the rise or versed sine of this arc being one-sixth of the span from centre to centre of the heel-posts. The back of the gate is the half of a circle of such a radius that at the middle of the gate it coincides with the arc of the gate. The front of the gate is a straight line from heel to mitre-post; with this form the recesses in the side walls will not be inconveniently large; the faces of the gates when open will, with the ordinary fenders, be in line with the side wall of the entrance, and the gangway at the top will form one straight path with the coping of the side wall, convenient for the gatemen carrying heavy warps backwards and forwards. As to the gate itself, the form would allow space for workmen to obtain access to the interior for repairs, and the width would give considerable flotation power. The straight face would permit of the gate being braced diagonally from the top of the heel-post to the foot of the mitre-post, and thus enable the greater part of the weight to be sustained by the anchor strap, to the relief of the roller.

The depositing dock, Figs. 997 and 998, a form employed with much success by Clark and Stansfield, differs from the other docks in as much as the vessel is not merely raised out of

997.



the water, but is deposited bodily in fixed staging along shore, so as to be virtually on dry land; the peculiar feature of the dock consists in the employment of a series of fingers or pontoons, which project beneath the vessel, and on which it is raised. These fingers are rigidly connected at one end, by a strong vertical side, composed of a very large tubular girder the whole length of



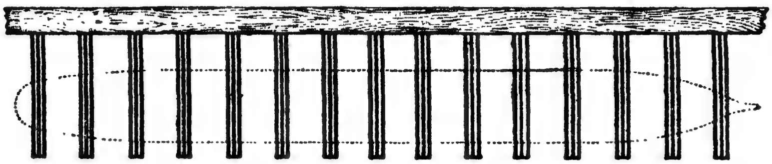
the dock, and which holds each pontoon rigidly in its position, the whole resembling the teeth of a comb. This girder, or side as it is termed, is of such a height that it is never quite submerged, although the pontoons which are attached to it are submerged sufficiently to allow the vessel to float over them. It contains the engines, pumps, and valves for working the dock.

In Fig. 997, A is the side of the dock, B the pontoons, and C the outrigger; this gives

stability to the dock, which is seen with the vessel resting upon it. In this case it may be used as an ordinary dock, the vessel being everywhere most conveniently accessible for repairs.

It is not essential to have depositing stages in the first instance, but the capabilities of the dock do not fully come into play unless these are provided. The stages are independent of the dock, and are formed of timber or iron piles firmly secured on the ground, and braced together, forming a number of narrow piers on which the vessel rests. These piers are about 5 ft. broad, and are usually from 10 to 15 ft. apart; the pontoons carrying the vessel upon them are arranged at corresponding distances, so as to float in between them. When in this position, by admitting a little water into the pontoons, the vessel is lowered on to the piers, where it is received on keel blocks and bilge blocks in the usual manner. Fig. 999 is a plan of the stage, the dotted lines indicating a vessel thus deposited on the piers. When the dock is removed from beneath the vessel, it is ready for repeating the operation. One dock can thus be used to rest and deposit a number of vessels, and again lift them into the water at pleasure.

999.



As the dock has only one side to it, special means are required for keeping it horizontal when at work; this is effected by the outrigger C, Fig. 997, which is a broad, shallow pontoon, floating on the surface close to the dock, and is provided with sliding grooves attached to the side; it maintains the dock in a horizontal position as it rises and falls. The stability thus given may be made as great as is desired, but it is usually arranged to equal that of a dock with two sides. In raising a vessel she is first brought over the dock, and secured in position by ropes and shores in the usual manner. Water is pumped out of the dock until it rises, and the vessel bears firmly on the keel blocks. Very broad sliding bilge blocks are then hauled under the bilges of the vessel, so as to form an unusually broad and stable cradle, and the pumping proceeded with till the vessel is fully raised. As regards the structure, both the side and pontoons are divided into a number of separate and watertight compartments, some of which are permanently sealed up, so that it is impossible to sink the dock either by design or accident. The middle portion of the pontoon, on which the chief weight of the vessel rests, is strengthened by extra frames and bulkheads; and as the pressure of the water on the submerged pontoons is sometimes equal to 15 lb. a square inch, a framework of iron is arranged within them, and also within the side.

The dock is constructed in two portions, each of which is complete in itself, and is provided with a separate set of appliances, so that either half may be used for docking small vessels. Each half of the dock is also arranged to raise the other half out of the water, without careening, so that either part is readily accessible at any time for cleaning and repairs. In depositing the vessel, this can only be done when the water is at a certain level, varying a few feet more or less, which difference can be adjusted by the blocking; where there is large fluctuation in the tide, the dock can only be used at or about high water; it is therefore desirable to arrange the position of the stages where there is no great variation of levels. The depth of water required between the stages is only that which is sufficient to float the pontoons, but at the spot where the dock is lowered to receive the vessel, a greater depth, equal to its draught added to the depth of the pontoons, is necessary. The total depth may generally be taken as one and a half times the draught of the vessel. If the general depth is not sufficient for this, the space will have to be dredged out to the required depth to receive the dock; when this is arranged it is surrounded by a framework of timber, which is first floated on in pieces to the spot, and then sunk into position by being loaded; the sides of the framework project about a foot above the general level, and thus prevent accumulation of sand or mud within the space. The dock is, however, provided with powerful mud pumps, and can at any time clear out its own body with facility.

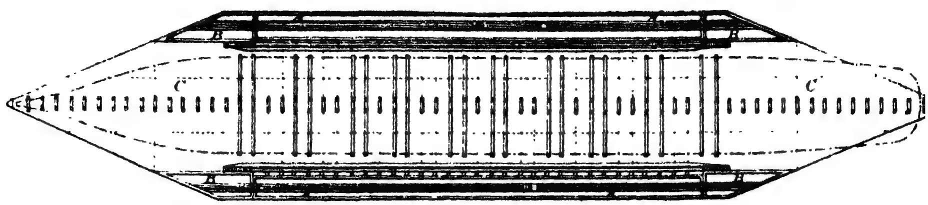
The pumps, engines, and valves are contained in the side of the dock, the pipes are divided into four groups, controlled by valves corresponding to the four corners of the dock, so that the level is regulated with ease.

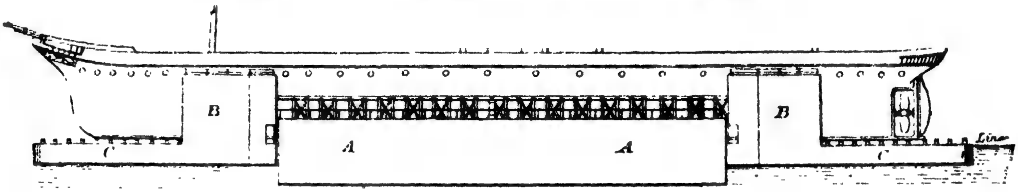
The outrigger which ensures the horizontal position of the dock when it is submerged, is a broad, flat, shallow pontoon, the whole length of the dock, divided into several portions, which are again subdivided into compartments. It is loaded with ballast until it floats to about half its depth. Each portion is attached to the dock by slight cast-steel slides, somewhat resembling the cross-head of a steam engine; they slide up and down on strong H-shaped irons, which extend the whole height of the side of the dock, by an arrangement of pins; any one of these can be detached or replaced with facility, and they are so fitted that they cannot set fast. As soon as the outrigger, or spirit level placed on the dock shows that the latter has any tendency to rise or sink faster on one side than the other, a slight adjustment of the valves will bring it back to its proper position. The outrigger pontoons may be utilized for carrying a pair of shear-legs, so as to form a floating derrick. This can be detached and used independently if necessary. It is stated that the time occupied in docking a vessel of the largest size does not exceed two hours, and the lowering occupies about half an hour. Smaller vessels can be raised, righted, and lowered again in about one hour and a half.

The depositing dock is not adapted to every situation, and Clark and Stansfield have designed a new dock, Figs. 1000 to 1002, termed a double-power floating dock, which was described to the Institute of Naval Architects in 1879 by Latimer Clark.

Fig. 1000 is a plan of the dock with a vessel outlined upon it, and Fig. 1002 an end elevation. B B are four corner towers rigidly attached to the body of the dock, and of such a height that they have a freeboard of about 5 ft. when the dock is at its lowest level; they are constructed with air-tight compartments; their object is to add to the stability while the dock is being raised and

1000.

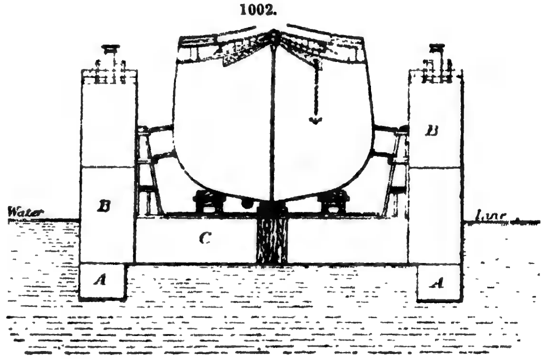




lowered, and to make the dock unsinkable even if all the valves were purposely left open. A A are the sliding parts of the sides; they extend along the greater portion of the length of the dock, and contain the engines and pumps. C is the pontoon or body of the dock, which is provided with pointed ends, in order that the buoyancy may be principally given under the heaviest part of the vessel, and to enable the dock to be towed easily.

Fig. 1001 is a side elevation with the vessel raised, and with the sliding sides A A lowered, so as to utilize their buoyancy. The sides are guided in their movement by a great number of steel slides attached to strong vertical side-shoring frames; these serve the double purpose of shoring the vessel and acting as guides for the movable sides.

1002.



The upper box slide is first secured by two pins to the shoring-frame slide; the side of the dock is now free to rise and fall, sliding through the box slides. As soon as the slide rises to the desired level, pins are inserted through the slotted holes in the box slide, and as soon as these pins take their bearing, the holes will also be fair to receive other pins, which will keep the side rigidly in position. The dock and sliding sides are now securely attached. These slides occur every 6 ft. on each side of the dock.

The two engines drive centrifugal pumps, controlling each side and each lateral half of the body of the dock. The power is communicated from the sides to the pumps in the body of the dock by means of bevelled wheels, one of which is fixed, and the other slides up and down on a grooved vertical shaft, fixed on the pontoon and connected with the pumps below. In very large docks there might be an advantage in placing the engines in the four corner towers, and in some cases the towers can be dispensed with.

Before lowering the dock to receive a vessel, the sides are fixed in such a position that the dock is in the ordinary form, and water being admitted in the usual manner, it sinks to the required level.

The vessel having been admitted, and slightly lifted and shored in the ordinary way, water is pumped out of the pontoon of the dock only, until the whole of its buoyancy has been brought into action. At this stage of the operation, the vessel being half raised, the water in the two sides is so regulated that they are successively made just self-supporting, and neither add to nor detract from the power of the dock. There are ready means for ascertaining this point. In order to complete the operation and bring the whole power of the dock into action, one of the sides is then unpinned, and water admitted into it until it descends to its lowest level, the top being allowed a freeboard of about 5 ft.; it is then rigidly pinned and secured in its new position, and the other side is lowered

and secured in a similar manner. It is now only necessary to pump water out of these sides to add their submerged buoyancy to that of the dock, and so complete the operation.

The hydraulic grid, designed by Clark and Stansfield, is similar to Edwin Clark's hydraulic dock, but the presses are sunk in the foreshore of a river, and placed beneath the vessel to be raised; the heavy guiding columns and cross girders can thus be dispensed with, as is also the pontoon, its place being supplied by a simple wrought-iron grid, upon which the vessel is shored and raised. This effects considerable economy in the cost of construction.

DRAINAGE.

In draining for agricultural purposes, a map of the land is first made from a careful survey, plotted to the scale of from 50 to 100 ft. to the inch, and the positions marked which may interfere with the regularity of the drains, such as large trees, rocks, and the like, together with existing swamps, springs, and open drains. The contour or horizontal lines of the land, that is, the lines of equal elevation, are then clearly marked, as they serve to show the shape of the surface; ~~the method of effecting this has already been described at p. 2371 of this Dictionary~~. With the maps so prepared, the plan of drainage can then be decided upon. Where masses of underground rock are supposed to exist, soundings should be made by driving a pointed iron rod down to the rock. In most cases it will be sufficient to have contour lines taken at intervals of 2 ft. only, but in many cases the skilled engineer will stake out the drains at once, by the aid of level and rod for the flatter portions, and by the eye alone for the steeper slopes; but this requires considerable experience.

The outlet should be at the lowest point of the boundary, unless for some special reason it is necessary to sink an outfall other than the natural one, and it should be deep enough to take the water of the main drain, and laid on a sufficient inclination for a free flow of the water; it should, where sufficient fall can be obtained without too great cost, deliver the water over a step of at least a few inches in height, so that the action of the drain may be seen, and also that it may not be liable to be clogged, by the accumulation of silt in the open ditch to which it flows.

The main drain should usually be run as low down in the principal valley as can be arranged, with due regard to regularity. It is better to cross the point of the hill to the extent of increasing the depth for a few rods, than to go a long distance off the direct course to keep in the valley, both because of the cost of the tile used in the main, and the loss of fall occasioned by the lengthening of the line. The main should be continued from the outlet to the point at which it is most convenient to collect the sub-mains, together with the water of several lateral drains; the depth of the main is often restricted, in nearly level land, toward the upper end of the flat which lies next to the outlet, by the necessity for the fall, and the difficulty which often exists in securing a sufficiently low outlet; where such is the case, the only rule is to make it as deep as possible. When the fall is sufficient, it should be placed at such a depth as will allow the lateral and sub-drains which discharge into it, to enter at its top, and discharge above the level of the water which flows through it.

Subsidiary mains connected with the main drains should be run up the smaller valleys of the land, skirting the bases of the hills where the valley is a flat one; with the rising ground on either side should be a sub-main, to receive the laterals from each hill-side. As a general rule, the collecting drain at the foot of the slope, should be placed in the line which is first reached by the water flowing directly over the surface, before it commences its lateral movement down the valley, and it should, if possible, be so arranged that it has a uniform descent for its whole distance. The proper arrangement for these collecting drains requires much skill.

Where springs are encountered, some provision should be made for collecting their water by digging a pit some distance below the level of the drain, and filling it in with loose stones, gravel, or other rubbish, or the water may be conveyed away by a line of tile run directly to the main. Where a large shelving ledge of rock occurs in land to be drained, it is advisable to collect at its base the water flowing over its surface, and take it to the main, so that it may not make the surrounding land unduly wet. To effect this, a ditch should be dug along the base of the rock, and quite down to it, deeper than the level of the proposed drainage; and this should be filled with small stones to that level, with the lines of pipe laid on top of the stones, a uniform bottom for the pipe to rest upon being formed. The tiles should be covered with inverted sods, to prevent the entrance of earth to choke them. The water falling down the surface of the rock will rise through the stonework, and entering the tiles, will flow off. This method may also be used with springy hill-sides.

The lateral drains constitute the real drainage of the fields; we shall assume in speaking of them, that they are to be applied to one of the more simple forms of drainage, that in which a large tract of land of uniform slope is drained by parallel lines of equal length, all discharging into the main running across the foot of the flat. It is best, in practice, to approximate as nearly as possible to this arrangement, because deviations from it, although always necessary in broken land, are expensive, and present a somewhat complicated problem. The depth to which the water should be withdrawn does not appear to depend upon the character of the soil, but upon the requirements of the crops which are to be grown upon it; and as these requirements are similar in nearly all cases, it is the practice of experienced drainers to place the lateral drains at a general depth of about 4 ft.; of course if the soil is underlaid by rock, less than 4 ft., and where an outlet at that depth cannot be obtained, it is not possible to drain so deeply; but where there exists no such obstacle, drains should be laid at a general depth of 4 ft., with a uniform inclination. The distance between the drains may vary considerably in accordance with the character of the soil. In tolerably porous ground 40 or 50 ft. is sufficiently near for 4-ft. drains; for the more retentive clays a distance of 18 to 26 ft. has been recommended; but there are few soils in which it will be safe to place 4-ft. drains at much wider intervals than 40 ft. An empirical rule that has been successfully employed in the lighter loams is, that 3 ft. drains should be placed 20 ft. apart, and that for each additional foot in depth the distance may be doubled; for instance, 4-ft. drains 40 ft. apart, 5-ft. drains 80 ft. With reference to this greater distance, it is not recommended in stiff clays for any depth of drain.

Where necessary, by reason of insufficient fall or hard substratum, to go only 3 ft. deep, the drains should be as near together as 20 ft. The direction of the lateral drains should be up and down the slope of the land, in the line of supposed descent. Very steep and very springy hill-sides sometimes require frequent drains, to catch the water which has a tendency to flow to the surface, but this rarely occurs.

In laying the plan for draining land of a broken surface, which inclines in different directions, it is not possible to make the drains follow the lines of deepest descent, and at the same time for them to be parallel and at uniform distances; a compromise must then be made between the two requirements. The more nearly they are parallel, the less costly will the work be, whilst the closer they follow the slope of the ground, the more efficient the drain will be. No rule can be given for these adjustments, but a careful study of the map and its contour lines will greatly aid in its determination. Wherever practicable, it is desirable to have a fall of 1 ft. in 100 ft., although one-half of that amount, or 6 in. in 100 ft., is ample if the work is carefully executed.

The lowest rate of fall which should be given to a drain in using a pipe is 2·5 in 1000, or 3 in. in 100 ft.

Agricultural drain pipes or tiles are made of the same material as ordinary bricks; their manufacture has been described at page 192 of this Supplement.

When burned they are from 12 to 14 in. in length, 1 to 8 in. diameter, and from ½ to more than 1 in. in thickness; the latter measurement depending upon the strength of the clay and the size of the bore. They are porous to the extent of absorbing a certain quantity of water, but this porosity does not affect their use in drainage, for the water enters them not through their walls, but in their joints, which cannot be made so tight that they will not admit the small amount of water that it is needful should enter at each space. Pipes may be of any desired form in section, but the round pipe with a collar is the only one which it is economical to use. Ground pipes should not be laid without collars, as the ability to use these constitutes their chief advantage; the collars hold them in place, preventing the entrance of loose dirt in the pipes, and giving the necessary space for the entrance of water by the joints. The usual sizes are 1¼ in., 2¼ in., 3¼ in. in interior diameters. The sections of the 2¼-in. pipes make collars for the 1¼, and the 3¼ make collars for the 2¼. In England 1-in. pipes are frequently used, but 1¼ in. are better for the smallest drains. Beyond this limit the best size is the smallest that can convey the water which will reach it after a heavy rain. The smaller the pipe the more concentrated the flow, and, consequently, the more thoroughly obstructions will be removed, and the occasional flushing of the pipe, when it is taxed for a few hours to its utmost capacity, will ensure a good cleansing.

The following dimensions of pipes suitable for various areas may be taken as reliable for drains 4 ft. or more in depth, laid in a well-regulated fall of as low as 3 in. in 100 ft. These sized pipes will not immediately remove all the water of the heaviest storms, but they will take it away fast enough for all practical purposes, and if the pipes are properly laid, will only be benefited by the occasional cleansing they will receive when running more than full.

Whenever it is possible to avoid it, no drain should have a decreasing rate of fall as it approaches its outlet.

The 1½-inch pipe will remove all the water which would fall on the ground in a heavy rain in twenty-four hours, and tiles of this size are ample for the draining of 2 acres; in like manner 2½-in. pipe will suffice for 8, and 3½-in. pipe for 20 acres, on the supposition that only the water which falls on the land, that is the storm water, is to be removed. For main drains when greater capacity is required, two pipes may be laid side by side. Where the drains are laid 40 ft. apart, about 1000 tiles to each acre will be required; the first 2000 ft. of drains require a collecting drain of 2½-in. tile, which will take the water from 7000 ft., and for an outlet of from 7000 ft. to 2000 ft., 3½-in. pipes may be used. Collars, being more subjected to breakage, should be provided in somewhat larger quantities. The pipes should be hard burned, and any rejected which do not give a clear ring when struck with a metallic instrument, and overburned goods, such as have been warped, contracted, or otherwise affected by too great heat, must be also rejected.

The danger that drains will become obstructed if not properly laid out and properly made, is very great, and the cost of removing the obstruction, often requiring whole lines to be taken up, washed, and relaid, with the extra care that is required in working in old and soft lines, is often greater than the original cost of the improvement. Consequently the possibility of tile drains becoming stopped up should be fully considered at the outset, and every precaution should be taken to prevent so disastrous a result.

Drainage of Mines.—In order to consider the subject of the drainage of mines, it is necessary to understand the manner in which water flows into the workings. The mechanical means employed to remove the water will be dealt with under the head of Pump.

Sedimentary rocks consist of permeable and impermeable beds, the latter composed of clays. Sandstones and limestones may contain various proportions of argillaceous matter, and the clays may be more or less largely composed of arenaceous and calcareous substances, so that the degree of permeability may vary within very wide limits. Sedimentary rock consists of an aggregation of small particles of pre-existent rock, compacted by pressure, and often cemented together by the infiltration of mineral substances. The interstices between these component particles are, when removed from the influences operating at and near the surface, always filled with water. A rock compacted by pressure will possess a greater water space than a rock of the same kind whose particles have been cemented together, because the cement partially fills up the interstices. A compact bed of sand will hold to each unit of volume a larger quantity of water than a cemented sandstone. The particles of argillaceous matter exist in a state of extreme division, so that the interstices are insufficient to allow the presence of water; therefore clay is impervious. As this substance is mingled with others, the interstices are filled up, and the argillaceous sandstone, for example, contains a much smaller water space than the purely arenaceous rock.

When an accession of water takes place in consequence of rain, the quantity of water passing through in a given time will again obviously be proportional to the water space existing in the rock.

It must not be assumed that because the nature of the rock is such as will give it a large water-bearing capacity that it is full of water; rock beds of a porous character are frequently passed through without any water being met with, and that a stratum may contain water the conditions must be favourable to its receiving water.

The source of underground water is rain, and the quantity received will depend upon conditions prevailing at the surface. If a lower and impervious bed is inclined, the water flows out of the upper and permeable bed towards the dip and the strike only, and not towards the rise, and the flow will be greatest towards the dip. These facts are to be considered in estimating the quantity of underground water likely to be met with.

The land surface is usually formed by the upturned ends of inclined strata, and this is the case always to be considered in dealing with the water in underground workings. In such a case the permeable stratum can receive water only along the line of its outcrop, and the quantity of water it can receive will depend upon the extent of that surface. Thus the extent of the absorbing surface is, as we have shown, to be estimated, not merely by the area of the stratum exposed, but also by that of the impervious strata which drains itself upon the former.

Rock beds are divided by joints, and fractured by faults of dislocation, and the joint spaces may be filled with water, and the fissures along the line of the fault may serve as passages through which water may flow in large quantities, or in which it may stand as in a reservoir. Existing under these conditions, water may be met with in the impervious beds, and in the igneous rocks; and in mining, the tapping of one of these reservoirs or water passages occasions the influx into the workings of a stream of water called a feeder.

The foregoing considerations enable a survey to determine the quantity of water likely to be met with in sinking at any given point, and to make provision against its entrance into the permeable strata by means of surface drainage. A consideration of the same facts will also enable judgment to be made whether a feeder is likely to be temporary or permanent, and also of the quantity of water it is likely to yield.

In judging of the effects of letting down the roof above which a water-bearing stratum is situate, the nature of the intervening rock must be taken into account. Beds of plastic clay sink without fracture, and shaly and marly beds may be broken down with a like result; for though fractures may, to some extent, occur in these, the fissures will close during the descent, in consequence of the yielding character of the material, and the water will not be let down in such a case. But if the rock is strong sandstone, and especially if it is of coarse texture, it will be greatly fractured in its descent, and the fissures produced left open. In this case, if only a very thin impervious bed intervene between the water-bearing bed and the sandstone, or if the intervening bed be somewhat permeable, the water will flow down copiously into the workings. The near presence of a fault is frequently indicated by an increasing degree of moisture in the rock. In the limestone, it is a common occurrence to meet with caverns and wide passages through which large quantities of water are circulating. These are called pounds and swallows; they are, doubtless, fissures which have been enlarged by the action of acid water.

Various means are adopted to prevent the influx of water into underground workings. Of these, some are applicable at the surface only, and they have for their object the lessening of the quantity entering the permeable bed. A system of drainage at that portion of the surface at which the beds or the faults crop out will greatly reduce the quantity entering. Any such system must include, to some extent, the contiguous impervious beds, from off which the water flows to the permeable bed. Hollows and streams upon the outcrop demand particular attention; often it may be desirable to divert the course of a stream; and in some cases it may be well to puddle its bed at certain points. An example of such a system of drainage is to be found in the basin of the Rive-de-Gier, France, a large portion of which coal-field could not have been worked, had the surface drainage not been provided for.

In combination with the surface drainage, means are employed underground to prevent the entrance of water into the workings. The method of stopping back the water in shafts by means of tubbing has been described under the head of Coal Mining. Of the precautions to be taken against the entrance of water, the chief relate to the breaking down of the roof; great care should be observed not to let down, by the dropping of the roof, water from ponds, reservoirs, and streams at surface.

The water which in greater or less quantities will always enter the workings of a mine, notwithstanding all the means employed to keep it out, must be removed to allow the operations of excavation to proceed. It is apparent that the only way of freeing underground workings of the water which has flowed into them is to convey it to surface When the workings are in a hill, and thus above the general level of the country, or above the level of a neighbouring valley affording an outlet, they may be drained by means of tunnels called adits, through which the water may be made to flow out. But when this favourable circumstance does not exist, the water must be pumped to surface. As the operation of lifting large quantities of water from great depths requires great power, the subject will be treated under a distinct heading. The principles of arranging the reservoir or sump of a pump have been already described in this Dictionary under the head of Drainage.

The drainage of sewers is a branch of sanitary engineering, and to the article upon that subject the reader is referred.

List of Books on Drainage.—STEVENS (H.), 'Manual of Practical Draining,' 8vo. PARKES (J.), 'On Land Drainage,' 8vo, 1848. FRENCH (F.), 'Principles, Processes, and Effects of Draining Land,' crown 8vo, cloth, 1859. WARING (G. E., jun.), 'Draining for Profit and Draining for Health,' crown 8vo. 'Johnston on Draining Land,' by ELKINGTON, 8vo, 1841. BALDWIN LATHAM, 'Sanitary Engineering, a Guide to the Construction of Works of Sewerage,' 8vo, 1878. ROBINSON (H.) and

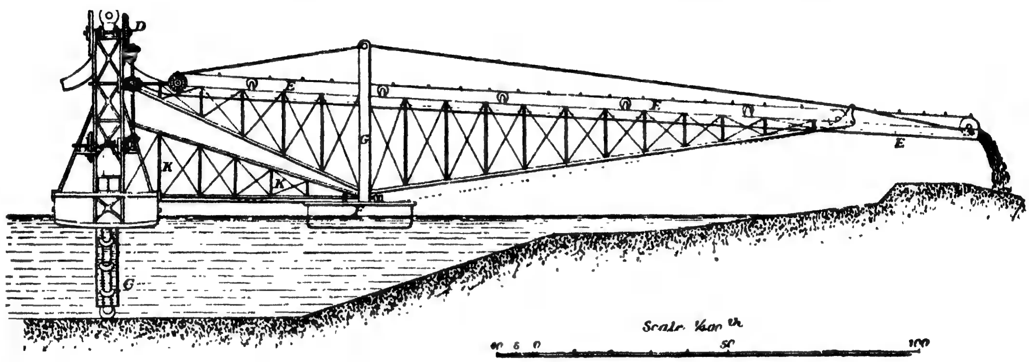
Mellis (J. C.), 'Purification of Water-carried sewage,' 8vo, 1877. Bailey Denton (J.), 'Sanitary Engineering,' royal 8vo, 1877. Burke (H. R.), 'A Handbook of Sewage Utilization,' crown 8vo, 1873.

DREDGING.

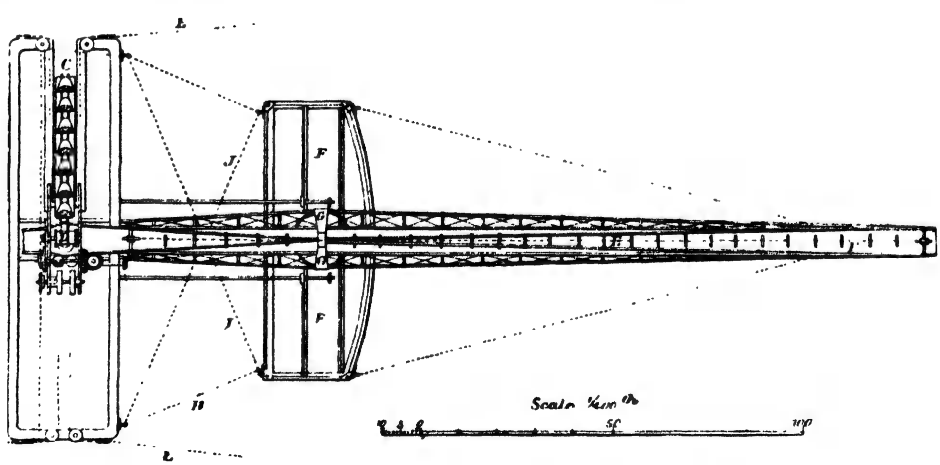
Dredging machines, to develop their greatest efficiency, should be designed to suit the special character of the ground on which they are required to work.

Notable examples of dredging plant are afforded by the machines employed in making the Suez Canal. The arrangement, Fig. 1003, presented the great advantage of doing away with cranes, ballast lighters, and especially waggons for removing the spoil, which, running over banks made of mud or wet clay broken up by the buckets, were constantly getting out of order. Moreover, with the aid of a few torches the dredger could be worked by night as well as by day.

The dredgers with the extra long shoots, Figs. 1003, 1004, are fitted with a single bucket frame C, the foot of which is ahead of the hull; the hulls are 108 ft. long and 27 ft. beam, and the upper tumbler D is 48 ft. in height above the water. The shaft of the engine carries a drum working two centrifugal pumps for supplying water to facilitate the discharge of the spoil



through the shoots. The length of the shoot C from the centre of the dredger is 230 ft., and its section is a half ellipse, $2\frac{1}{2}$ ft. deep and 5 ft. wide; the width of the vertical well into which the buckets discharge the spoil being greater than that of the shoot, a tapering junction is made of as great a length as possible. The shoot is stiffened lengthwise by two lattice girders, which rest on



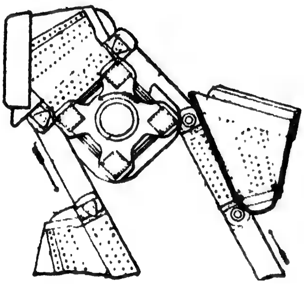
the bottom of an iron lighter F, placed at about one-third of their length from the dredger; the uprights G supporting the shoots are not fixed to the bottom, but jointed to a large horizontal spindle placed lengthwise in the lighter, and passing along its centre of displacement. A horizontal hinge couples the shoot to the dredger, and allows of its inclination being altered; this joint is covered by a piece of leather and iron, being fixed to the dredger only. In order to allow of changing the inclination of the shoot, the uprights G resting on the lighter are made telescopic. The shoot is lifted by two small hydraulic presses worked by hand; blocks of a suitable thickness are then put into the slides of the uprights G, and the whole is bolted together.

For the purpose of facilitating the transport of the shoots, the framework supporting them is cut in two horizontally above the slides just mentioned, so that when the shoot is detached from

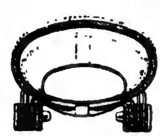
the dredger, it can be turned on a sort of platform and brought into a position lengthwise with the lighter, the outer end being put upon a boat for that purpose. As it is necessary that the dredger in traversing across the canal from side to side should carry its shoot and lighter with it, the lighter is connected to the dredger transversely by a pair of chains, H H, Fig. 1004, with horizontal struts at right angles to the two hulls to serve as distance pieces; and a second pair of chains J J run from the stern and bow of the dredger to the bow and stern of the lighter, whereby they are securely stayed together longitudinally. A pair of iron frames K K fixed to the dredger, and resting on the lighter and attached to it, make the two hulls like one piece in their vertical movements.

The swinging movement of the dredger is performed by means of chains L L, Fig. 1004, from the four corners of the dredger to anchors with very broad and strong flukes. These chains pass through hawse holes 3 to 5 ft. below the water, leaving sufficient depth of water above them for the boats used on the canal to pass over the chains; the hawse holes are found to wear away very quickly.

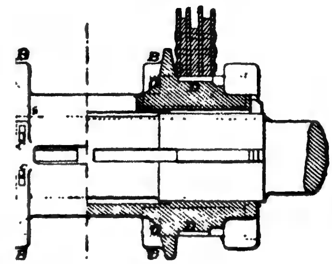
Only one form of bucket is used, of elliptical section and very conical, as shown in Figs. 1005, 1006; and as this empties very easily, it has not been considered necessary to try any other forms. It should be borne in mind that, beyond a certain size, the buckets empty very well even when they work in sticky clays; because the adhering surface of the spoil is simply proportioned to the square of the dimensions, whereas the volume, and consequently the weight of the spoil, is



1006.



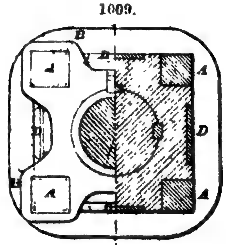
1007.



proportional to the cube of the same dimensions. Thus the weight increases more quickly than the adherence, and consequently the latter is always overcome beyond a certain limit of dimensions. Fig. 1007 is a plan of a portion of the chain.

The upper tumblers of the dredgers, Fig. 1005, of which Fig. 1008 is an elevation and section —Fig. 1009 is part elevation and part section at the end, Fig. 1010 being a transverse section at the centre—are made of cast iron, the angle-pieces, consisting of a square steel bar A A at each of the four corners, passed through the flanges B B of the tumbler, and secured by a key C. Each of the four wearing faces of the tumbler is also protected by a steel plate D D, let in with a dovetail and secured by screws.

1009.



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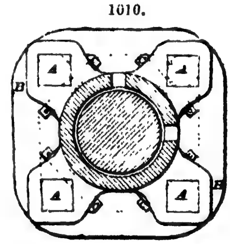

The following observations have been made as to the manner in which the different sorts of spoil pass down the shoots of the dredgers. The fine sands, which are the only sands met with, pass easily down a shoot inclined 1 in 20 or 25, if mixed with a quantity of water equal to about half their own bulk. When the shoot has a less inclination than 1 in 25, the water separates from the sand, which is thus deposited all along the shoot in layers of continually increasing thickness; the addition of a larger quantity of water does not seem to have any effect, and it is necessary to stir it up with a shovel.* When the sand contains any shells, they are deposited in the shoot even with an inclination of 1 in 20, notwithstanding their lightness; and create round them deposits of sand, which continually increase, and have to be got rid of with shovels, or better still, by increasing the inclination of the shoot. In this case again an increased quantity of water is not so efficacious as increasing the inclination. Different degrees of fineness and muddiness in the sand, and different sections more or less flattened of the shoots, require different inclinations of shoot.

Mud behaves very much like sand, if it is sufficiently soft to mix with water; and it will then pass down a shoot set with scarcely any perceptible inclination. The very softest mud at Suez, such as that got out of the old channels previously cut through the clay ground, does not require the addition of any water in the shoot. With clay it is quite different; the addition of water washed away only a very small quantity of the material, and hardly breaks up the lumps at all. If each lump of clay were to slide perfectly straight down the shoot, all would work well; most commonly, however, a lump winds about and soon stops, and the contents of the next bucket then drive it on 5 or 10 ft., and the whole increases the block. Others come after and increase the stoppage, till the mass gets 12 or 16 in. in thickness and reaches to the top end of the shoot, when the contents of the succeeding buckets seem to break it up, and the mass descends quietly and regularly

in pieces of about 3 to 6 ft. length. The shoots for clay are inclined from 1 in 12 to 1 in 16. With an inclination of 1 in 20 the lower end gets choked, which tilts that end of the shoot down and empties it, the work being thus carried on intermittently; with an inclination of 1 in 12 to 14 the work is more regular. When the clay is mixed with sand, the surface acts like a rasp, because the water washing away the clay makes the grains of sand more prominent and cutting, and thus seems to be rather detrimental. This is also the case when the buckets bring up hard clay and mud; the mud lubricates the clay and makes it run down more easily, whereas the water only washes the mud away.

Experience has thus shown that whilst a considerable supply of water must be added to sand, it is not so for mud or clay, to which only just enough water must be added for moistening the mass. Jets of water have not given good results; they merely wash down the points against which they are directed, and do not break up the lumps. The simplest and most convenient plan has been to put up a footway along the side of the shoot, and keep three or four men at work with scrapers to prevent its choking. In the long-shoot dredgers, with shoots of 230 ft. length, an endless travelling chain E is employed, as in Fig. 1003, driven by the engine, and furnished with a series of scrapers to carry the clay down the shoot. Generally the greatest difficulty with all kinds of spoil is in passing the first 40 or 50 ft. length of the shoot; when once the material has passed this with any given inclination, it continues moving on down the same inclination without further difficulty.

An efficient tool for difficult ground is R. J. Ives' excavator for stiff clay, Figs. 1011, 1012. The excavator lock, at the back, is first pushed into place, a light line being attached to the lock. The blade is now open or vertical with the monkey guide-rod, in which position the excavator is lowered on to the bottom to be dredged, where the apparatus is kept upright by the lowering chain being held slightly taut. The monkey is now worked up and down the centre guide-rod, by the line attached to it, leading over a pulley fixed on a staging at the top. The monkey, being allowed

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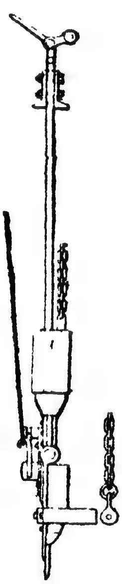

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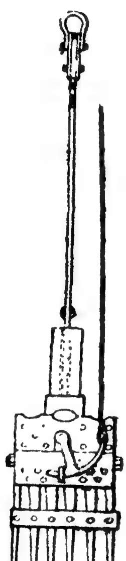

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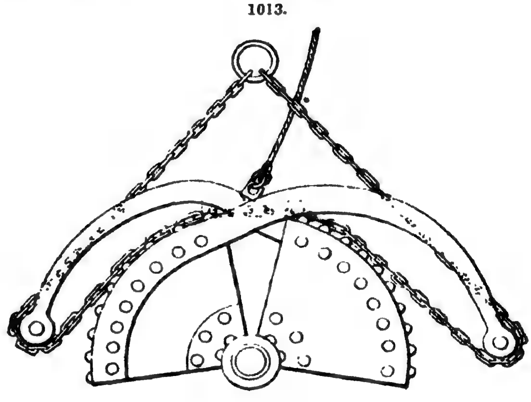
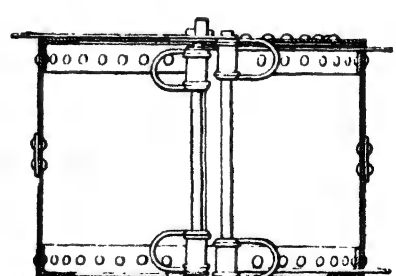




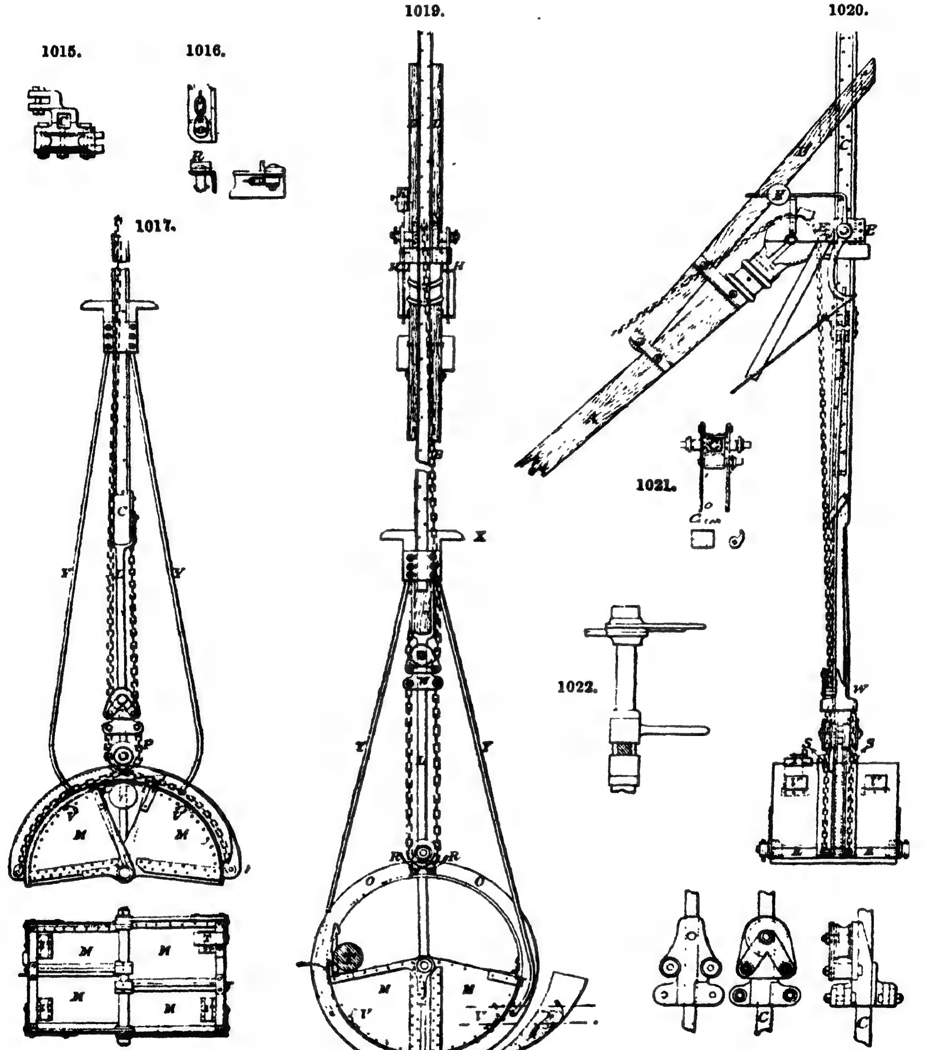
1014.

to fall by its own weight, gives a sharp blow to the head of the excavator, and drives the blade into the ground at each blow. After a sufficient number of blows the locking gear is pulled, which draws out the locking bolt, and releases the blade from its vertical position; when this has been done, the lifting chain is hauled by the crab, and the blade dragged out of the ground with its load, in a position at right angles with the monkey guide-rod. Continued hauling on the lifting chain brings the whole to the surface where the material so excavated is tipped. The locking gear is again pushed into place, and the apparatus lowered into the clay bottom for another operation.

Bull's dredger, Figs. 1013, 1014, is lowered by a crab and tackle working from a pulley fixed to a gallows or sheer-legs, erected on a stage. Before lowering, the clip or double pin, Fig. 1013, is inserted into holes in the two segments; this keeps the dredger open until it reaches the bottom, when the clip is withdrawn by means of a stout cord. The lowering chain attached to the chains working in guides and small rollers at the four corners of the dredger, is then pulled up slightly, agitated, and lowered. By these means the jaws of the dredger are gradually drawn together, scooping up the sand or loose material. The number of times the chain is so pulled

depends on the material to be dredged. With loose soil the jaws soon meet, when the dredger is drawn up, opened on the staging and the materials fall out; the clip is then again inserted, and the operation repeated. In sand, the time occupied for each operation of lowering, dredging, and lifting is five or six minutes, where the distance from the top of the staging to low water is 25 ft.; from low water to the bottom of the curb, 46 ft.

The dredging apparatus, Figs. 1015 to 1026, is designed by C. Fouracres, and used in India; it consists of two segmental scoops M, hinged on a cross-head firmly welded to a wrought-iron spear L, attached by a key to a light wooden spear C. Two metal collars, W X, slide freely on these spears,

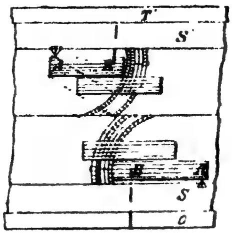


1015. 1016. 1017. 1018. 1019. 1020. 1021. 1022. 1023.

the upper is connected to the scoops by a light iron rod Y, and the lower by two chains. One end of each of these chains is connected to the collar, and the other, after passing through one of the sheaves P, is attached to one of the semicircular angle-irons O; the chain on the right hand of the spear being attached to the angle-iron which is riveted to the right scoop, and the chain on the left of the angle-iron to the left scoop. These chains then cross each other around the sheaves P, and since the semicircular angle-irons also cross at the same point, the chains when placed in tension tend to close the scoops one upon the other in the position, Fig. 1019. The angle-iron riveted to one scoop wraps itself round the other scoop when the bucket is opened, as in Figs. 1017, 1018. Both the angle-irons are chipped and filed to a segment of the true circle on their upper edges, which bear against friction rollers revolving on the same pin which carries the sheaves Q, and that tends to preserve the angle-irons in their proper shape. The sliding collar W has a sheave within it, round which the main lifting chain B is rove. When working in soft soil, the chain B is attached directly to the collar W, and when in hard soil, power is gained by passing the chain through the sheave, and fastening the end of it to the spear, as in Fig. 1019. This main

chain is worked over the head of the crane, Fig. 1020, stops R and S being provided to prevent the scoops overrunning themselves, and thus getting jammed. T is a float catch hinged to the top of one of the scoops, and when they are open, it hooks on to a lug on the top of the other scoop. It thus ties the two scoops together at the top and prevents them from closing, as the catch remains in its position. The hooks H, which are attached to the jib head, are so counterbalanced by the

1024.



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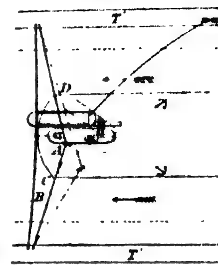
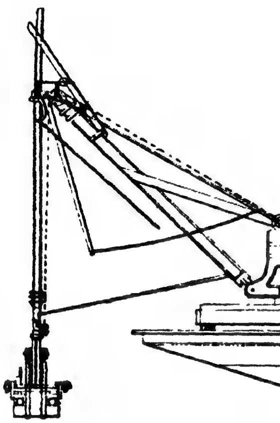
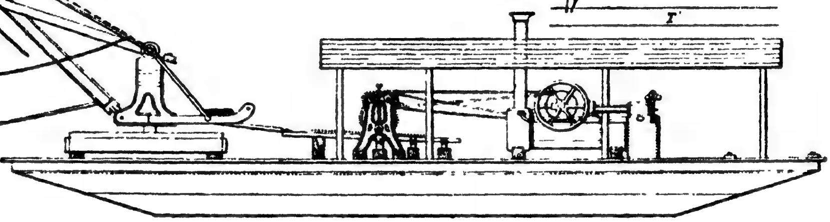


1026.

weight K that they fall forward into the position, Fig. 1020, when the rope attached to them is slack. These hooks have sloping faces at their lower extremities, so that when the clutch collar X rises up to them, the projecting arms of the collar push back the hooks and rise past them; when the arms are above the hooks the latter fall forward and support the arms so as to prevent the collar from returning. In this position the main lifting chain may be lowered and the whole apparatus hangs by the hooks H on the jib head; the entire weight is thus thrown on the collar X, and the scoops are drawn open into the position, Fig. 1017. The lever E is centred on the jib head, and has attached to it a cam which bears on a shallow rack fixed to C; on pulling the rope attached to the lever, this cam jams the spear in the guide so that it cannot rise. V V are leather valves which allow water to escape if the bucket is not filled with mud, but which are closed up, and retain any solid matter the scoops may cut into. In working, the main lifting chain B is attached to a winding engine, or to a crab winch, or through a machine which will enable the man who regulates the machinery to wind up the chain or unwind it, or hold it stationary at any moment. The dredge is lowered into the water in the position Fig. 1017, by unwinding the main chain. While being lowered the chain is tight, as it bears the entire weight of all the movable parts of the dredge. The strain on the main chain tends to draw the travelling collar W upwards on L; this tightens the closing chains, the strain on which, acting on the semicircular angle-irons O, tends to close the scoops of the bucket. The catch T, however, holds the two scoops together at the top and prevents them from closing. In this manner the wooden spear C descends, the bucket sliding freely on the guides D and E; when the bucket reaches the bottom, which it generally does with somewhat of a blow, if the engine is run quickly, the scoops rest on the surface of the mud if open slightly, and the strain is taken off the catch T, which immediately rises out of gear by the floating of the ball attached to it, the scoops are released and free to close. The stops S prevent the scoops from opening more than is sufficient to release the catch T. Upon the scoops reaching the bottom, the attendant reverses the machine and winds up the main lifting chain, at the same time the lever E is pulled over by the rope attached to it, and jams the spear tightly on the guide. As the main lifting chain ascends, it draws the collar W upwards on L and with it the chains, which cause the angle-irons O to press the scoops into the material in which they were resting. The spear is meanwhile held fast by the lever and cannot rise; thus the scoops are compelled to bite into the soil. But if any other hard matter is met with, the pressure on the spear causes the cam to jump out of the shallow rack and no damage is done. As soon as the bucket is closed, which is known by watching the point to which the collar X descends on the spear, the lever is released and the apparatus rises to the surface by the continued action of the main lifting chain; when the bucket clears the water the crane is revolved, until the bucket hangs over the mud punt alongside, Fig. 1026; as the clutch collar X rises the projecting arms push back the hooks, which immediately afterwards fall back into position underneath the arms. The winding of the chain is then reversed, the rods Y take the whole weight of the apparatus, the spear and heavier parts descend, and the scoops are pulled open partly by the weight of the contents and partly by that of the descending parts, the whole of which press upon the cross-heads of L, and thus tend to open the scoops. When they are wide open the stops R bear on the spear L, and the catch T falls automatically into position, catching the other scoop. The dredger is now ready for another bite, the slack of the main lifting chain being taken up, and the weight of the apparatus being removed from the hooks H, sufficiently to enable them to clear the arms of the clutch collar. The hooks are then drawn back, the crane revolved, and the operation repeated. The engine, or winch which it works, has to be

reversed three times during each lift: after lifting the clutch collar from the hooks when it has to be reversed to lower the bucket; after the bucket reaches the bottom when it has to be reversed to lift; and when the bucket is over the mud punt in order to empty it. In the dredgers constructed upon this system, the rapid reversal of the motion of the main chain has been effected by sliding-forks on the crab, which move direct and cross straps alternately on the tight pulley.

Fig. 1062 shows the dredger complete and arranged for operation.

The dredger was first started for Indian canal work, with the regulating apparatus designed by Fouracres, being secured in position, as shown in Fig. 1024, by a T-strut, the base of which was fastened to the bank by two pins. In this figure T′ indicates the towing path and S′ the slope of the embankment. The further end of the strut was fitted with an eye, which worked on a pin attached to the stern of the dredger at A. This strut fixed the point A, and the dredger was only able to revolve about that point as a centre. To the other end of the dredger a piece of quartering was attached, working at B on another pivot similar to the one at A. This quartering was of sufficient length, to allow the bow of the dredger to be moved a few feet beyond the centre of the canal. The quartering was marked into divisions of 4 ft. each, which was the width of the bite of the bucket. After the bucket had taken its first bite the boat was pushed off the distance of one of these divisions of 4 ft., by men on the bank working a small twofold tackle. Thus, each time the bucket was lifted the dredger was moved out the distance of 4 ft., and the bow of the dredger compelled to work in the arc of a circle. If it was found that one bite of the scoops was not sufficient to clear out the canal to the requisite depth, two or three bites were taken at the same spot, or the dredger was run a second or third time over the same arc. When it was necessary to move the dredger forward to work on a new arc, the T-strut at A was shifted about 2 ft. 6 in. along the bank, that being the width of the bucket used; and the dredger was thus set to cut another arc parallel to the last.

This arrangement, though an excellent one when working near a bank, or in a narrow canal where there is much traffic, was not found useful for dredging a channel of 50 ft. down the centre of the canal, which was the work required to be done. Indeed it seems doubtful whether a well-arranged system of anchors would not always be more convenient for working this dredger. The arrangement, Fig. 1025, was therefore adopted. A small gipsy winch A was fitted on two uprights at the edge of the dredger. A small capstan would have been more suitable, since the regulating chain B would not have jammed on a capstan as it did sometimes on the winch. By turning the winch A, it was easy to regulate the movements of the dredger, causing it to oscillate in the arc C D. Two anchors attached by ½-in. chains to a bollard on the stern of the dredger kept the point I very nearly stationary, the action of the current tending to keep the anchor chains tight. Occasionally, as the stream varied, the dredger would perhaps float slightly out of its proper course, in which case the buckets might come up very nearly empty; but this did not occur very frequently. When the dredger had worked up to the point D, the anchor chains were slackened and the dredger moved forward about 2 ft. 6 in.; the man regulating the dredger then reversed the winding on the winch A, and gradually brought the dredger back to the point C, and so on continually. Occasionally, when the anchor chains became long and the dredger was perhaps somewhat swept off her course by the action of the current, or when the anchor chains had been slackened by more than the proper amount, a ridge of silt would be left which the dredger had to be brought back to cut; but generally the channel was cut very clearly.

Some difficulty was at first found in managing the mud punt in the stream; the silt came up so hard and dry that it would not spread itself over the deck, and it was necessary to move the punt frequently, so that the silt might be uniformly deposited. An arrangement of hooks on the punt and small bollards on the dredger was, therefore, adopted; by this the labourers were able to draw the punt by hand into any required position, and fasten it to the bollards on the dredger by small pieces of rope. Two pairs of bullocks towed the full punts to the river, and brought the empty ones.

On the works for regulating the Danube at Vienna, the work of discharging the dredged material out of boats, usually done with spades, or with skips raised by cranes, has been performed by redredging the material out of the boats, with a machine designed for the purpose. Staging is erected projecting from the bank into the river, and a beam, turning at one end on an axle at the top of the staging, carries at the other end a wheel. There is also a drum on the top of the staging, and a chain with dredge buckets turns round the drum and the wheel. The beam is raised or lowered by a 5 or 6 horse-power engine, and it can also be moved a little transversely, so that the material may be readily and completely removed from boats moored under the staging. The unloading is performed by a 12 to 15 horse-power engine, which raises 200 to 260 cub. yds. of gravel an hour; but less than half this amount of work is accomplished when the boats are loaded with clay or sand mixed with mud. The material drops from the buckets into a shoot, and thence into waggons running on a tramway on the top of the stage, communicating with the land. A boat containing about 46 cub yds. can be unloaded, and another boat put in its place in ten minutes; and several of the machines have discharged 392,400 cub. yds. of material in a year. The dredgers have brought up twice this quantity in a year, the filling into boats being very easy; so that one dredger supplies material for two machines. A staff of fifteen men is required for working one machine, including shunting and arranging the waggons in trains. Sometimes a float is employed, the staging being fixed on two boats with an intervening space for the boat that contains the material, and a movable platform, worked by an endless chain, is used for conveying the material beyond the shoot. This form of machine is useful for embanking sides of rivers and making dikes.

A dredging machine has been at work on the Garonne, constructed by Popie, and consists of a shallow, flat-bottomed boat, 51·5 ft. in length by 6·6 ft. in width, fitted with paddles near the bows, which communicate with the dredger by a chain passing over a pulley, fixed on uprights, and under a roller on the deck. The scoop is an iron box, 2 ft. wide and 2·5 ft. deep, attached

to the end of a strong beam which passes through a well hole, 14·8 ft. long, in the bottom of the boat.

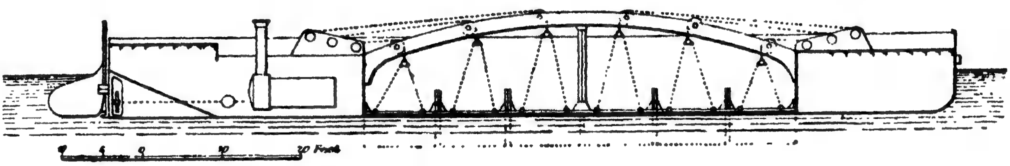
When the boat is anchored in the stream, the force of the current, acting on the paddles, winds the chain on a windlass, dragging the scoop along the bottom of the river up through a well hole and above the receiver. A lever rod attached to the scoop enables it to be opened, and the gravel to be discharged by a shoot into a boat moored alongside; after which the chain is slackened and the dredger again lowered. The boat is made to draw on its anchor by a cog-wheel fixed on the axle of the paddles and working on a winch. When the stream is not sufficiently strong, a man with a windlass can work the dredger. The paddles are raised out of the water by means of two uprights and pulleys, when it is desired to stop work.

1027.

With an ordinary swift current at Agen, they can obtain one discharge of the scoop a minute, or 65 cub. yds. of gravel a day of twelve hours.

Several classes of ballast barges have been tried; one which has been adopted, Fig. 1027, is a hopper-decked barge, of French pine, to hold 50 tons of material, 39½ ft. long and 17½ ft.

1028.



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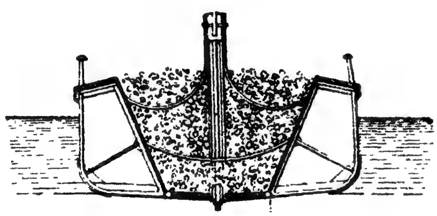

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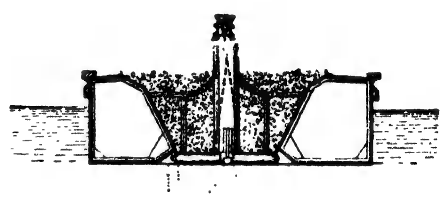
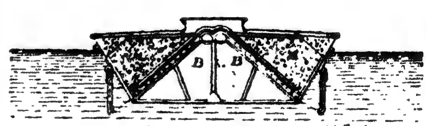
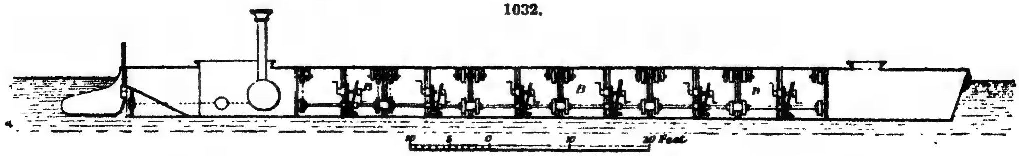


wide. The advantage of this form is that the water brought up by the dredger flows over the sides of the barge when it is nearly full, leaving the sand almost dry. It will likewise float although the internal compartments may be filled with water. The material dredged, sand and mud, is conveyed in the barges to the discharge stage, near the centre of the station, and lifted to a height of 21 ft. above high-water ordinary spring tides. The hoisting machinery is worked by shafting, driven by a 12 horse-power portable engine. The shafting drives two sets of gearing, working each two grooved winding drums, 16 in. in diameter, with ⅝-in. chains coiling in contrary directions, so that whilst one jib is lifting the other is lowering. The skips hold 22½ cub. ft. of material, weighing 1700 lb., and discharge their contents into tip waggons working upon a platform immediately below. The weight of the empty skip is 485 lb., making a total weight of 2185 lb.

1031.



1032.



On the Suez Canal works, various forms of ballast barges were used, the design, Figs. 1029, 1030, being arranged with bottom doors for discharging in the lakes, Fig. 1028 being a modification adapted for use at sea; Figs. 1031, 1032, are arranged with side doors for discharging in shallow water.

The lighters with bottom doors are shown in Figs. 1028 to 1032; they are 108 ft. long and 23 feet beam, carrying 160 cub. yds. of spoil, and drawing 5 ft. of water. They are fitted with

twin screws and a pair of cylinders placed end to end; the engines work at high pressure without a condenser, with a tubular boiler at 120 lb. pressure, using only fresh water. Whether loaded or light they make a good speed of 3 to 3½ miles an hour, and although made specially for lake work, they can put to sea. Their construction is simple and economical; and it is found that high-pressure engines are preferable to those of a medium pressure, as being simpler, lighter, and easier to keep in working order, and consequently more to be relied on for continuous work.

DYNAMO-ELECTRIC AND MAGNETO-ELECTRIC MACHINES.

A magneto-electric machine is a mechanism intended to create electric currents by the help of magnetism. The term magneto-electric is confined to those machines in which the magnetism is obtained from permanent magnets. When permanent magnets are replaced by electro-magnets, the term dynamo-electric is used. The term dynamo-electric is, of course, applicable to any form of machine, such as a frictional electric machine, by which work is converted into electricity, but custom has limited its use.

The same principle underlies the action of all magneto- and dynamo-electric machines, that the cutting of a line or field of magnetic force, by a closed wire circuit, induces in the wire an electric current. The direction of this current varies with the direction of motion and the polarity of the magnetic field.

If a bar magnet is introduced into a coil of insulated wire, an electric current appears in the wire, if the circuit is closed. Entry and withdrawal of the magnet induces currents opposite in direction. An electro-magnet may be substituted for the bar magnet with similar, but generally enhanced, effect. These facts are those utilized in the construction of dynamo- and magneto-electric machines.

Pixii's machine, invented in 1832, consists of an electro-magnet attached to the upper part of a framework, and a magnet arranged to revolve rapidly before the electro-magnet, pole to pole. A handle and a pair of bevel wheels suffice to rotate the magnet. When movement is imparted to the magnet, its poles are made to pass successively before the poles of the electro-magnet. There is induced in the wire of the coils, at each half revolution, a current which passes into the conducting wires. This current is alternately direct and inverse, and for many applications must be caused to take one direction. This is effected by means of a commutator on the axis of rotation, upon which press springs in connection with the conducting wires. The commutator consists of two halves of a cylinder completely insulated one from another by a bad conductor. If each half cylinder be connected with one of the poles of a voltaic battery, when the cylinder is at rest, the friction springs are affected by a direct current; but when the cylinder rotates, the current collected by the friction springs will change direction. If the cylinder be put on the axle of a machine, so as to turn with it, and the one half cylinder be connected to one coil of the electro-magnet, and the second half cylinder to the other, the currents collected are always in the same direction, because the current in the electro-magnet changes its direction at the same instant that the friction springs change on the half cylinders.

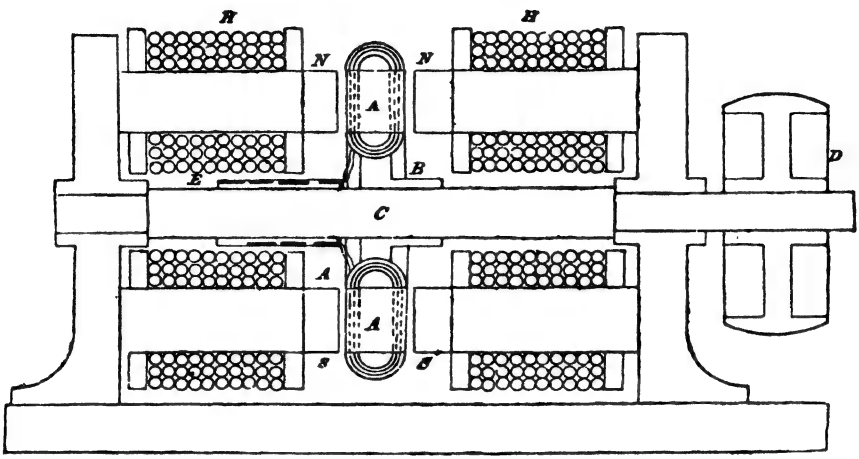
Clarke's machine consists of a bundle of horse-shoe magnets. Before this bundle two bobbins are revolved, by means of a bevel wheel and small crown wheel mounted on the axle of the coils. The coils are wound on two cylinders of soft iron, connected together by the same metal. A commutator at the extremity of the axis redirects the currents.

A. N. Breguet's machine resembles Clarke's machine, but in the latter, however rapidly the currents are made, they are not absolutely continuous, whilst in the former, by modifying the rotating bobbins, there is obtained a perfectly continuous electrical current. A circular disc is mounted on a horizontal axis. Twelve bobbins are inserted in this disc. The bobbins are connected together as so many elements of a galvanic battery, and form one continuous length. The electrical condition of each bobbin, when in movement, may be inferred from Lenz' law, that an inverse current is induced when a conductor approaches a pole of a magnet, and a direct current when it is withdrawn from the pole. Suppose the whole armature of coils of wire to revolve from left to right, all the bobbins on the left will be traversed by a current in one direction, and all those on the right by a current opposite in direction, but equal in volume to the former. The apparatus may be compared to two distinct batteries, consisting of six elements each connected together for tension. To effect the union of the two batteries for quantity, two metallic springs are attached to two small uprights which are the terminals of the magneto machine. Twelve strips of copper are disposed radially, and to them are attached the two adjacent ends of each pair of bobbins. The metallic springs act as current-collectors; and as they are always in contact with several of the radial strips, they must always be traversed by electric currents. Hence the perfect continuity of the current developed by this machine, which is serviceable in cases requiring high tension but small quantity.

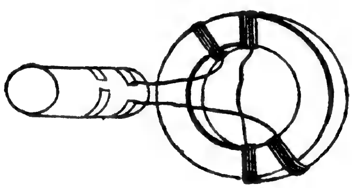
Figs. 1033 to 1036 are of the Brush dynamo-electric machine. The iron armature of this machine is in the form of a ring, and is attached to a hub. This hub is rigidly attached to the shaft C, which when driven by the pulley, causes the armature to revolve in its own plane. The armature is provided with grooves or depressions, in a direction at right angles with its magnetic axis or length. These grooves are wound full of insulated copper wire. The sections of wire thus formed are of any suitable number. The advantage of winding the wire on the armature depressions is twofold;—The projecting portion of the armature between the sections of wire may be made to revolve very close to the poles N N and S S of the magnets, from which the magnetic force is derived, thus utilizing the inductive force of the latter, to a much greater extent than is possible in the case of annular armatures entirely covered with wire, which cannot be brought very near the magnets. Owing to the exposure of a considerable portion of the armature to the atmosphere, the heat, which is always developed, by the rapidly succeeding magnetizations and demagnetizations of armatures in motion, is rapidly dissipated by radiation and convection. In the case of armatures entirely covered with wire, the escape of heat is very slow, so that they must be run at a comparatively low rate of speed to prevent injurious heating.

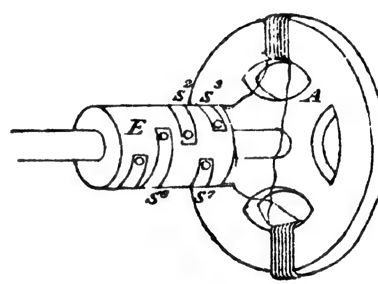
Diametrically opposite sections of the armature may have their first or last ends joined together, and their remaining ends connected with two segments of metal of the commutator cylinder, which is carried by the shaft, and is of insulating material. The two metal segments are placed diametrically opposite each other on the cylinder, and are each of a length less than half the circumference

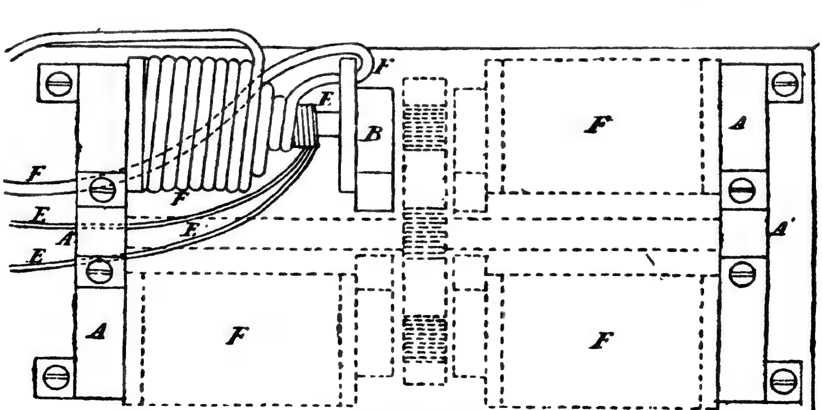
1033.



of the latter, thus exposing the insulating cylinder in two places diametrically opposite each other and alternating with the metal segments. The two segments S^3, and S^7, Fig. 1035, corresponding to sections 3 and 7 of wire, hold a position on the cylinder, in advance of those of the preceding sections S^2 and S^6, to the same angular extent that the sections 3 and 7 in question are in advance of sections







2 and 6. In this arrangement the number of segments is equal to the number of sections, each segment being connected with but one section. The first and last ends of each section can, however, be attached to two diametrically opposite segments, the commutator cylinder in that case being constructed with double the number of segments as in the former case, thus making the number of

segments double the number of sections. Two metallic plates or brushes, insulated from each other, press lightly upon the cylinder, at opposite points, so selected that while each section of wire on the armature is passing from one neutral point to the other, the corresponding segments on the cylinder will be in contact with them. These plates or brushes collect the currents of electricity generated by the revolution of the armature, one being positive and the other negative. When the section of wire is passing the neutral points on the armature, the plates are in contact with the insulating material of the cylinder between the corresponding segments, thus cutting the section, which is at the time useless, out of the circuit altogether. The necessity of thus insulating each section from the plates during the time it is inactive, is obvious, otherwise the idle section would afford a passage for the current generated in the active sections.

During the time a section or bobbin is passing from one neutral point of the armature to the next one, an electric impulse, constant in direction but varying in electro-motive force, is induced in it. This electro-motive force, starting from nothing at the neutral point, quickly increases to nearly its maximum, and remains almost constant until the section is near the next neutral point, when it rapidly falls to zero as the neutral point is reached.

The insulating spaces are made of such a length that each section or bobbin is cut out of the circuit, not only when it is at the neutral points, but also during the time when its electro-motive force is rising and falling at the beginning and end of an impulse.

If the insulating space is too short, so as to keep or bring a section in the circuit while its electro-motive force is low, then the current from the other sections, being of superior electro-motive force, will overcome this weak current, and discharge through this section. If the insulating spaces are a little longer than necessary, no material inconvenience results. A suitable length for practical purposes is easily determined experimentally. It is necessary to adjust the commutator cylinder on the revolving shaft of the machine, with special reference to the neutral points of the armature when in motion, in order that its insulating space may correspond to the neutral points. This adjustment is made as follows. The commutator cylinder having been placed approximately in its proper position, the machine is started, and the presence or absence of sparks at the points of contact between the plates and commutator cylinder is noted. If sparks occur, the commutator cylinder is turned slightly forward or backward on its axis until they disappear.

The presence of sparks, when the commutator is even slightly out of its proper position, is easily explained. If a break between a pair of segments and the plates occur while the corresponding section of wire on the apparatus is still active, a spark is produced by the interruption of the current, while if the break occurs too late, the section in question will have become neutral, and then commenced to conduct the current from the active sections, and the interruption of this passage causes a spark in this instance. If the commutator is much removed from its proper position in either direction, the sparks are so great as to very rapidly destroy both the commutator and the brushes, while the current from the machine is diminished.

When the first and last ends of each of two diametrically opposite sections are attached to two opposite segments, the intensity of the induced electric current will be that due to the length of wire in a single section only, while the quantity will be directly as the number of sections. By doubling the size of each bobbin, and diminishing their number one-half, a current of double the intensity and one-half the quantity of the former will be obtained.

This effect can also be secured by connecting the first and last ends of the two opposite sections together, and joining the remaining ends to two opposite segments, Fig. 1034. This arrangement of the cylinder with segments may be replaced by another, in which the last end of one section, and the first end of the succeeding one, may be connected with a strip of metal attached to the cylinder, parallel with its axis, as in the Siemens and Gramme machines.

These metallic strips or conductors are equal in number to the sections of wire on the armature, and are insulated from each other. The plates press upon the cylinder, in this case, at points corresponding to the neutral points of the armature, thus being at right angles with their position in the first arrangement. This plan gives fair results, but is subject to a disadvantage from which the first is free. The difficulty is that the sections of wire, when at or near the neutral points of the armature, contribute little or no useful effect, but the current from the other sections must pass through these in order to reach the plates, thus experiencing a considerable and useless resistance; and, owing to the opposite directions of the currents through the active sections on opposite sides of the neutral points, these currents, by passing through the idle sections, tend strongly to produce consequent points in the armature where the neutral points should be, thus interfering with the distribution of the magnetism of the armature.

The electro-magnets H, are excited by the whole or a portion of the electric current derived from the revolving armature. The arrangement in which the magnetic poles are presented to the armature is such, that a very large proportion of the entire surface of the armature, is constantly presented to the poles of the magnets, thus securing uniformity of magnetization as well as maximum amount. The iron segments B, Fig. 1101, constituting the poles of the magnets, are arranged on both sides of the armatures. These pieces may be connected at their outer edges, thus forming one piece, and enclosing the armature still more. Permanent steel magnets may be employed in these machines, instead of electro-magnets.

By diverting from external work a portion of the current of the machine, and using it, either alone or in connection with the rest of the current for working the field magnets, a permanent field may be obtained.

This plan is adaptable for electro-plating machines. If the external circuit be broken entirely, the magnetic field will in the former plan remain unimpaired, and in the latter remain sufficiently strong to effect the desired end.

The cores of the field magnets are wound with a quantity of a comparatively fine wire E, having a high resistance in comparison with that of the external circuit F, and the rest of the wire in the machine. The ends of this wire are so connected with other parts of the machine, that when the

latter is running, a current of electricity constantly circulates in the wire, whether the external circuit be closed or not. The high resistance of this wire, prevents the passage through it of more than a small proportion of the whole current capable of being evolved by the machine. When this device, termed a teaser, is used in connection with field magnets, also wound with coarse wire, for the purpose of still further increasing the magnetic field, by employing the main current for this purpose, then the teaser may be so arranged, that the current which passes through it will also circulate in the coarse wire, thus increasing efficiency.

1037.

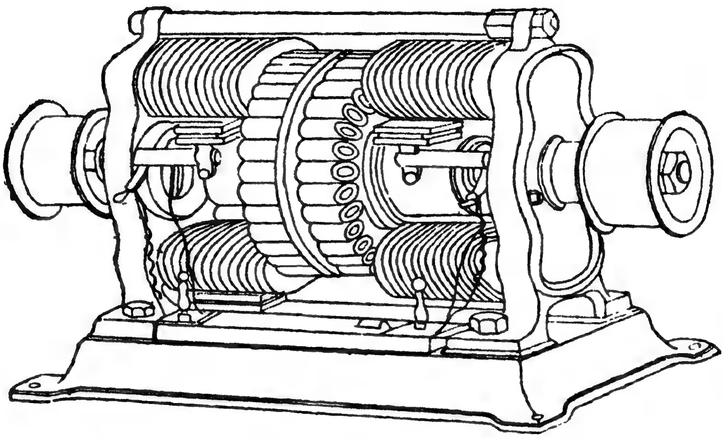
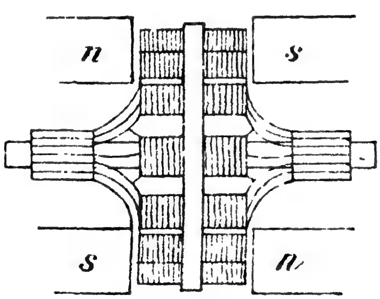
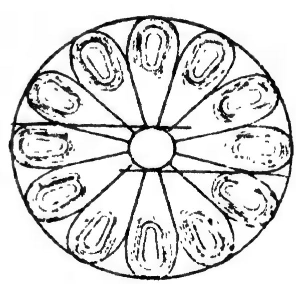


Fig. 1037 is of the Wallace-Farmer machine. In this machine the magnetic field is produced by two horseshoe electro-magnets, with poles of opposite character, facing each other. Between the arms of the magnets, and passing through the uprights supporting them, is the shaft, carrying at its centre the rotating armature. This armature consists of a disc of cast iron, near the periphery of which, and at right angles to either face, are iron cores, wound with insulated wire, thus constituting a double series of coils. These coils, Figs. 1038 and 1039, being connected end to end, the loops so formed are connected in the same manner, and to a commutator of similar construction to that of Gramme. As the armature rotates, the cores pass between the opposed north and south poles of the field magnets, and the current generated depends on the change of polarity of the cores. This constitutes a double machine, each series of coils, with its commutator, being capable of use independently of the other; but in practice the electrical connections are so made, that the currents generated in the two series of armature coils, pass through the field magnet coils, and are joined in one external circuit.

1038.



1039.



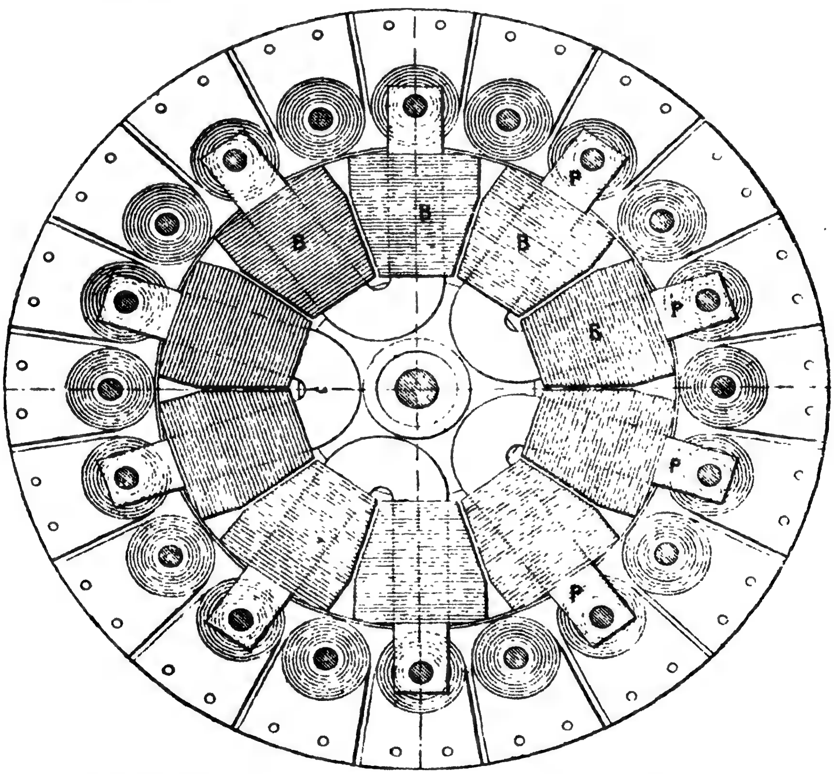
This armature exposes a large uncovered surface of iron to the cooling effect of the atmosphere, but its external form gives great resistance to rotation. In the Wallace-Farmer machine there is considerable heating of the armature, the temperature being sufficiently high to melt sealing wax.

Siemens and Halske's machine, of 1854, consists of a longitudinal coil, the iron of which is cylindrical in form, hollowed out parallel to its axis in two large and deep recesses, so that its transverse section resembles an I. The copper wire, insulated, is wound in the recesses parallel to the axis of the cylinder, and, with part of the iron left uncovered, constitutes a complete cylinder. One end of the wire is soldered to the metallic axis of the cylinder, and the other to a metal ring insulated on the extremity of its axis. The armatures of the magnet embrace the coil very closely, just allowing its rotation. The coil acts as the iron keeper generally furnished to magnets to prevent loss of power.

The Alliance machine, invented by Nollet and Van Malderen, is constructed with a number of bronze plates each carrying at its circumference 16 coils. These plates are mounted on

a horizontal axle actuated by a motor through a belt, and revolve between eight series of compound magnets, set radially round the axis, and supported parallel to the plane of the plates by a special framework. As each magnet has two poles, one series presents 16 poles regularly distanced. There are an equal number of poles and coils, so that when one coil is facing a pole, the 16 others are also facing poles. These machines have four or six plates corresponding to 64 coils and 40 permanent magnets, and 96 coils and 56 permanent magnets respectively. One of the poles for the total current is attached to the axle, which is in communication with the frame by means of the bearings; the other pole terminates in a ring concentric to the axle and insulated from it. The current changes its direction every time a bobbin passes before the magnet poles. As there are 16 magnet poles, there are 16 changes a revolution, and as the machine makes 400 revolutions a minute, there will be at least 100 changes of direction a second,

At every change of polarity the intensity of the current should pass zero. Thus 100 times a second the spark ceases to play between the two carbons in an electric lamp, but the light does not appear discontinuous. This is owing to the persistence of light on the retina, also that the true voltaic arc only produces a fraction of the electric light, the remainder being due to the incandescence of the carbons. The tension of the current is insufficient to cause the spark to play to the distance between the cold carbons, but when these are raised to incandescence by the passage of the current, the surrounding atmosphere becomes better conducting, by the elevation of temperature and the presence of carbonaceous particles; the duration of the interruptions being very short, the properties of the atmosphere surrounding the carbon have not time to become sensibly modified, and the current recommences to pass.



In Holmes' magneto-electric machine for the production of light, introduced in 1869, Fig. 1040, instead of the coils revolving before the magnets, the magnets revolve before the coils. Part of the current produced is employed to magnetize the electro-magnets; and the coils can give several independent circuits, and produce several independent lights in each circuit.

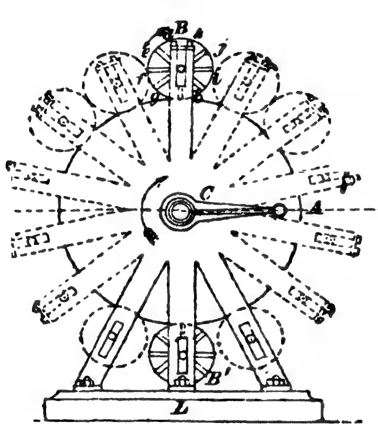
Wilde's machine consists of two Siemens' apparatus superposed and of unequal dimensions, with the modification that in the larger the magnet is replaced by a powerful electro-magnet. The upper and smaller machine is intended to magnetize the electro magnet, and is termed the exciting machine. A longitudinal bobbin revolves between the two arms of the magnet, developing alternating currents, which are redirected by a commutator, and led to the electro-magnets by two terminals. Beneath is a large electro-magnet, the two branches of which are constructed of plates of sheet iron; and for the elbow of the horseshoe is substituted an iron plate carrying the exciter. The poles of this electro-magnet are masses of iron separated by a copper plate, and form a cylindrical cavity in which revolves the second Siemens' bobbin. This part of the apparatus is

called the generator. The two bobbins are similar, but the diameter of the larger is three times that of the other. The exterior conducting wires are attached to its poles. The insulated copper wires which cover the branches of the large electro-magnet are carried to terminals of the exciter. By the aid of two driving belts and a motor the two bobbins are caused to revolve, the smaller with a velocity of 2400 revolutions a minute, the larger with a velocity of 1500 revolutions a minute. The currents induced in the exciter maintain the larger electro-magnet strongly magnetized, and the currents induced in the generator are utilized in exterior work. Their intensity is greater than the currents from the exciter.

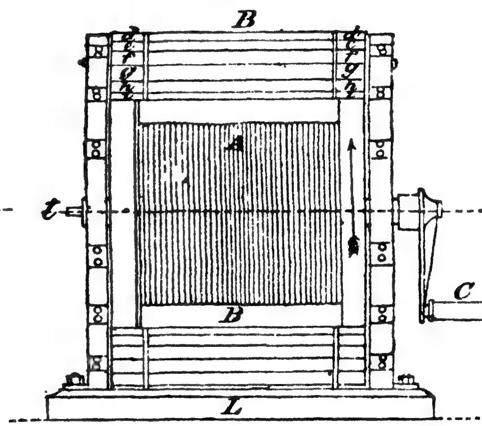
Ladd's machine consists of two parallel electro-magnets; at the extremities of these are placed two Siemens' bobbins of different sizes. The small bobbin excites the electro-magnets, and these react on the large bobbin which furnishes the working current. The wires from the electro-magnets are so connected that the contrary poles will be in relation when a single current passes. The free ends of these wires are carried to terminals, where they receive the currents from the small bobbin. Ladd's machine is also based upon the principle of mutual accumulation, discovered by Wheatstone, in which the exciting electro-magnets are included in the main circuit, and by reciprocal action induce currents of great strength in the revolving portion of the machine, whilst themselves fed from this revolving portion.

Trouvé's machine is composed of two or more electro-magnets in permanent magnetic contact, and participation in a rotary movement, like the trains of a rolling mill. The magnetic and electric circuits are both closed. The exits and entrances of the currents are made through the hollow axles, which admit in the centre the insulated conductors. Figs. 1041 and 1042 represent front and side views of this machine. It consists of a strong, straight electro-magnet, influencing a series

1041.



1042.



of straight electro-magnets, forming a circular bundle. The whole system is set in rotary motion by the large electro-magnet, which also serves as a fly-wheel. The machine gives either reciprocal or continuous currents according to the arrangement of the commutator. It is either magneto- or dynamo-electric according to the employment of permanent or electro-magnets.

If the motion is as indicated by the arrow, all the electro-magnets, *d e f g*, placed at the left of the perpendicular, passing by the centre or axis, approach the large electro-magnet, which affects them, and generates in their respective bobbins positive currents; all the electro-magnets on the right of the perpendicular *h i j k*, receding from the great electro-magnet, are influenced by negative currents. A special commutator collects these currents, either to use them in quantity or in derivation, or to give them in tension.

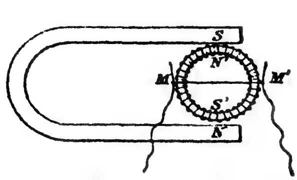
Fig. 1043 represents a Gramme machine arranged on this principle. M M′ are two electro-magnets in permanent contact, by their opposite poles, with the discs N N′, thus forming a single magnet, for which one of the discs serves as a shank, and the other as an armature, constituting a completely closed magnetic circuit. Fig. 1044 represents in section one of the two discs N N′, which are mounted on the common axle O. When they are set in motion, they communicate a rotary motion to the two electro-magnets, which influence them continually and thus generate currents in the series of bobbins which form the discs. The contact becomes more complete between M M′ and N N′, in proportion as the currents are stronger.

A, Fig. 1107, is a large electro-magnet, serving as a fly-wheel to the crank C, or to a pulley mounted on its axle; B B′, a cluster formed of the small electro-magnets *d e f g h i j k*; L, the base. P P′ P″ P‴, friction springs, collecting the currents generated in the discs; *t t′ t″* extremities of the coils of the electro-magnets. This machine yields for each, of its discs, a light equivalent to 4800 candles.

Rapieff's machine consists of several ring-shaped inductors A A A, Fig. 1045, and several armatures of the same shape and arrangement, B B B are disposed alternately side by side in planes normal to their common axis, the spaces between them being rendered as small as possible. The armatures B B B are fitted on a common shaft, wherewith they are caused to rotate, while the inductors A A A being secured on a frame or stand, remain fixed; or inversely.

S and N of a magnet, the soft iron is magnetized by induction, and there occur in the ring two poles, N′ and S′, opposed to the poles S and N. If the ring revolves between the poles of a permanent magnet, the induced poles developed in the ring remain in the same relation with regard to the poles N and S, and are subject to displacement in the iron itself with a velocity equal, and of

1049.



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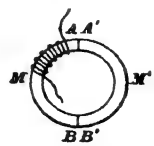

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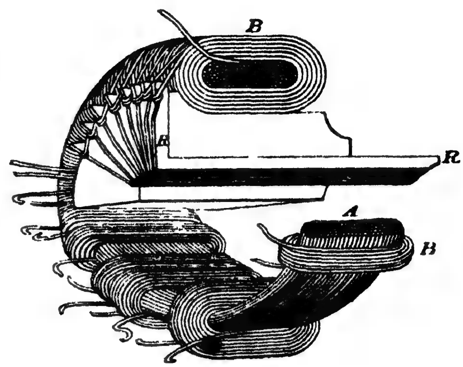
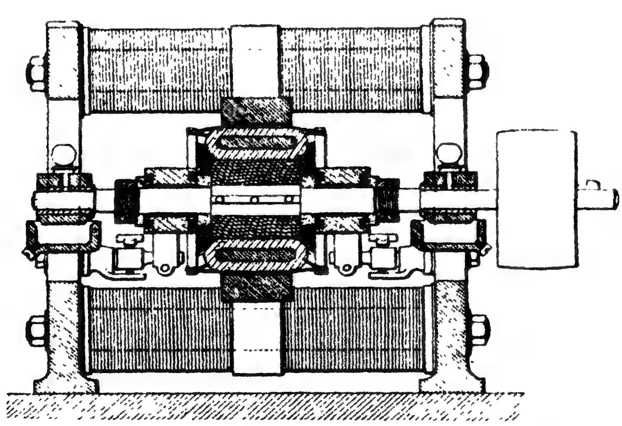


contrary direction to that of the ring. Whatever the rapidity of the movement, the poles N′ S′ remain fixed, and each part of the copper helix successively will pass before them.

An element of this helix is the seat of a current of a certain direction when traversing the path M S M′, and of a current of inverse direction to the first when passing through the path M′ N M. All the elements of the helix possess the same property, all the parts of the helix above the line M M′ will be traversed by currents of the same direction, and all parts beneath the line by a current of inverse direction to the preceding. These two currents are equal and opposed, and balance one another. As when two voltaic batteries composed of the same number of elements are coupled in opposition, it is necessary only to put the extremities of a circuit in communication with the poles common to the two batteries, and the currents become associated in quantity. Collectors of the current developed in the ring are established on the line M M′, where the currents in contrary direction encounter each other.

Insulated radial pieces R, Fig. 1050, are each attached to the issuing end of a coil, and to the entrant end of the following coil. The currents are collected on the pieces R, as they would be on the denuded wire. Their bent parts, brought parallel to the axle, are carried through and beyond the interior of the ring, and are brought near one another upon a cylinder of small diameter. The friction brushes on the pieces R are in a plane perpendicular to the polar line, and at the middle or neutral points. The intensity of the current increases with the velocity of rotation; the electromotive force is proportional to the velocity. Effects of tension or of quantity are produced by winding the ring with fine or coarse wire. With equal velocities of the ring the tension will be proportional to the number of convolutions of the wire; but the internal resistance increases in the same proportion. Thick wires give the best results.

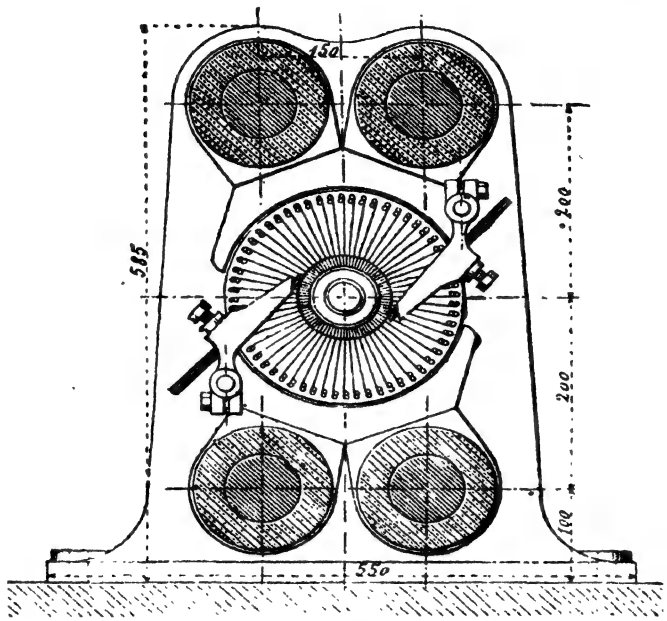
Various machines have been constructed on the Gramme principle for experimental purposes. The first type of this apparatus was horizontal, and gave a current equivalent to nearly three ordinary Bunsen elements. Since the invention by Jamin of laminated magnets, nearly all the laboratory machines have been constructed with magnets on this system.



Gramme's first light-machine gave a light of 7000 to 8000 candle-power. Its total weight amounted to 2200 lb. It had three movable rings and six bar electro-magnets. One of the rings excited the electro-magnet, the other two produced the working current. The copper wound on the electro-magnets weighed 550 lb; that of the three rings, 165 lb. The space required, 31½ inches length, by 4 ft. 1½ in. height. This machine lighted the clock-tower of the Houses of Parliament. It became slightly heated, and gave sparks between the metallic brushes and the bundle of conductors on which the current was collected.

Figs. 1051 and 1052, the latter to an enlarged scale, are of a machine which consists of two standards of cast iron arranged vertically, and connected by four iron bars serving as cores to electro-magnets. The axle is of steel, its bearings are relatively very long. The central ring,

1052.



instead of a single wire attached by equal sections to a common collector, is formed of two wires of the same length, wound parallel on the soft iron, and connected to two collectors to receive the currents. The poles of the electro-magnet are of large size, and embrace seven-eighths of the total circumference of the central ring. Four brushes collect the currents produced. The electro-magnet is placed in the circuit. The total length of the machine, including the pulley, is 31½ in.; its width, 1 ft. 9½ in.; and its height, 23 in. Its weight is 880 lb.

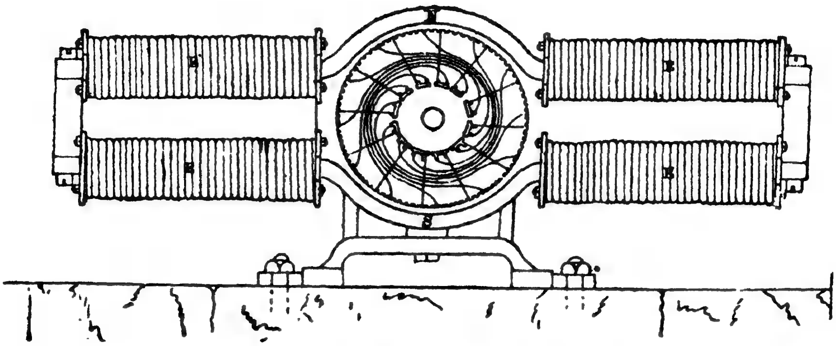
The double coil is connected to 120 conductors, 60 on each side. Its exterior diameter is 8 in. The weight of wire wound on is 31 lb. The electro-magnet bars have a diameter of 2½ in., and a length of 15⅝ in. The total weight of wire wound on the four bars is 211 lb. The winding of the wires on the ring is effected as if two complete bobbins were put one beside the other, and these two bobbins may be connected in tension or in quantity. Coupled in tension, they give a luminous intensity of 6400 candle-power at 700 revolutions a minute; coupled in quantity they give 16,000 candle-power with 1350 revolutions a minute.

The following Table I. gives the results obtained with a Gramme machine of the workshop type, a Serrin lamp, and Gaudoin carbons. The motive power employed did not exceed 2 horse-power, when the machine was making 820 revolutions, and 3 horse-power at 900 revolutions. The lamp was distant 200 yards from the machine feeding it, and kept at a height of 15 ft.

TABLE I.—EARLY EXPERIMENTS WITH GRAMME MACHINES.

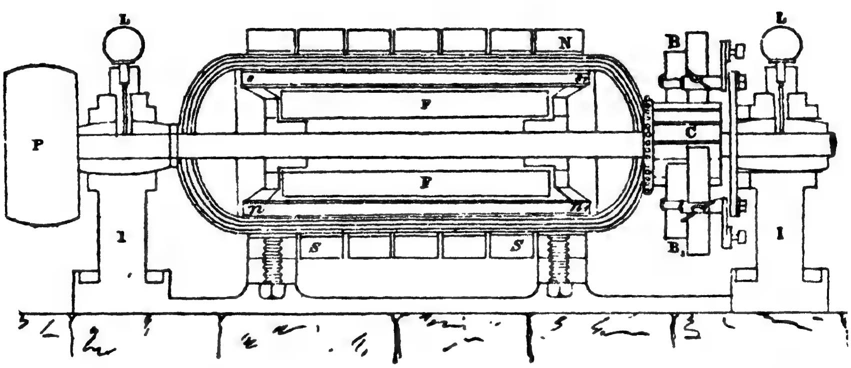
No. of Revolutions.	Distance of Observer from Lamp.	Candle-power Light.	Remarks.
	feet		
820	135	2464	The current was too feeble to maintain the carbons ⅛ in. apart.
820	67½	3600	
820	30	4120	
820	15	4800	Distance apart ⅛ in. regularly. Working satisfactorily.
820	7½	4896	
870	135	3200	
870	67½	4400	
870	30	6480	
870	15	8800	Too high tension. The carbons heat for considerable length. The light unsteady.
870	7½	9040	
920	135	3616	
920	67½	5632	
920	30	9656	
920	15	11362	
920	7½	11520	

The electric current is produced in Siemens' dynamo-electric machine, Figs. 1053 and 1054, by the rotation of an insulated conductor of copper wire or armature coiled in several lengths, say 8, 12, 16 up to 28, and in several layers, longitudinally, upon a cylinder with a stationary iron core $n\,n_1\;s\,s_1$, so that the whole surface of the armature is covered with longitudinal wires and closed at both ends.



This revolving armature is enclosed to the extent of two-thirds of its cylindrical surface by curved soft-iron bars.

The curved bars are the prolongations of the cores of the electro-magnets E. The coils of the electro-magnet form, with the wires of the revolving armature, one continuous electric circuit, and when the armature is caused to rotate, an electric current, at first very feeble, is induced, by



the remanent magnetism in the soft-iron bars, and directed through the collecting brushes into the electro-magnet coils, thus strengthening the magnetism of the iron bars, which again induce a still more powerful current in the revolving armature.

At each revolution the maximum magnetic effect upon each convolution of the armature is produced just after it passes through the middle of both magnetic fields, which are in a vertical plane passing through the axis of the machine. The minimum effect is produced when in a plane at right angles or horizontal.

Induced currents are collected by brushes B, placed in contact with the commutator in the position which gives the strongest current.

The circumference of the revolving armature is divided into an even number of equal parts, each opposite pair being filled with two coils of wires, the ends of which are brought out and attached to a commutator.

The machine gives the following results for the various sizes;—

Revolutions per Minute.	Illuminating Power. Standard Candles.	Horse-power.	Weight.
			lb.
850	1,200	2	280
650	6,000	4	420
360	14,000	8	1,288

Only one Siemens or Serrin lamp can be burnt in the circuit of one of these machines.

The Gramme and similar machines are reversible; the rotation of the bobbin gives rise to an electric current; and reciprocally, if a current traverses the bobbin, the latter is caused to revolve. Because of this complete reversibility, all theories should be equally acceptable for both functions

of the machine. The usual demonstrations do not fulfil this condition; but A. Breguet has shown that if the Gramme ring be considered as an extension of Barlow's wheel, theoretical views can be taken of the greatest simplicity. As is well known, Barlow's wheel consists of a metallic conductor, bent twice at right angles, and supported at the middle of its length on the point of a vertical axis, the axis of rotation of the system. The bent branches are parallel with this axis, and dip at their lower ends into a circular canal containing mercury; this canal is divided by ebonite partitions into equal parts, which are connected to the poles of a battery. The current from the battery passes to one semicircular canal of mercury, up one bent arm of the conductor, along the horizontal member, and down the other bent arm to the other semicircular canal of mercury. The whole apparatus is placed between the poles of a powerful permanent magnet, so that the diameter formed by the ebonite partitions is perpendicular to the line joining the magnet poles. On completion of the circuit, the conductor commences and continues to rotate. Breguet, to simplify explanation, terms the diameter formed by the partitions the diameter of commutation; and the magnetic field developed by the currents of the moving parts, the galvanic field, to avoid confusion with the magnetic field properly so called. If several convolutions are substituted for the single wire, the moment of revolving force will be increased proportionately to the number of the convolutions, provided that the resistance introduced by the increased length of wire does not sensibly reduce the strength of the current.

If a continuous frame be formed, so that in four crossings the wire on the upper part of the frame, as it is brought up, is at right angles to the crossing by which the wire was carried down, an approximation to the Alteneck or Siemens armature is obtained, the commutation in this case being arranged by four pieces pendent from the lower part of the frame.

If an iron cylindrical ring be arranged so that the axis of this ring is parallel to the axis of rotation of the wire conductor, which passes up the outside of one diameter of the cylinder, down upon the inside of the cylinder, across to the inside of the cylinder upon the farther part of the diameter, returning to the mercurial commutator by the outside of the cylindrical ring, an approximation is obtained to the Gramme ring. The iron cylinder acts as a magnetic screen, shutting off the action of the permanent magnet upon the interior wires, as in the Gramme machine.

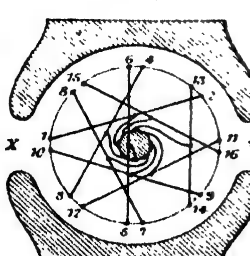
Breguet's views confirm the experiments made by Lippman, which go to prove that magnetic screens acting as armatures cease to fulfil this function when under movement of translation. This arises from the ring or screen, which in a state of rest concentrates or deviates upon itself the lines of force, when in movement taking up and abandoning an equal number of these lines in a given time, rendering its concentrative effect nil.

If d be the diameter, and e the width or length of a Gramme or Alteneck bobbin, the length of wire necessary to complete convolution is in the Gramme bobbin $4e$, and in the Alteneck bobbin $2(e + d)$, no account being taken of the extra length due to superposition of the layers of wire. If $4e < 2(e + d)$, the Gramme will be more effective, and if $4e > 2(e + d)$, less effective, than the Alteneck machine; if $4e = 2(e + d)$, the two machines will furnish identical currents. This equation being equivalent to $e = d$, according as the width or length of the bobbin is less or greater than its diameter, so will the Gramme machine be superior or inferior to that of Alteneck. Breguet considers that a drawback to the efficiency of the Alteneck machine is the necessity of fastening down the wires on the cylinder by bands, to prevent the wires, during centrifugal action, bowing out into contact with the exciting magnets, because these bands prevent the active wires being brought in such close proximity to the exciting magnets as in the Gramme machine, where the shortness of the wire does not call for this binding down.

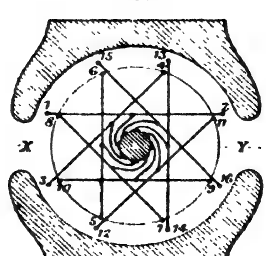
Whilst the soft-iron armature of the Alteneck machine serves merely to reinforce the magnetic field in the region of the moving circuit, the annular core of the Gramme machine withdraws the internal wires of its armature from the normal action of the lines of force of the field. The angular displacement of the commutator occurring with such machines is not due to retardation consequent upon time necessary to magnetize or demagnetize the soft-iron cores, because such angular displacement occurs with machines not possessing iron cores; and if the machine is to be used as an electromotor converting electricity into mechanical work, the angular displacement of the commutator brushes should be in a direction opposite to that of the rotation of the armature, and in the same direction as that of the rotation when the machine is employed as a generator of electric currents.

The following are various methods of winding the coils of the armatures of dynamo-electric machines described by Breguet.

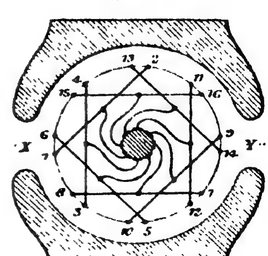
1055.



1056.



1057.



The wire is wound longitudinally on a cylinder, of which Fig. 1055 represents one of the ends. All the convolutions traverse the opposite end by one of the diameters. Starting from 1, the wire crosses the nearer end by 1, 2, and returns by 3 from the farther end of the cylinder, and so on.

Fig. 1055 shows how each transversal branch is connected to the eight metallic sectors, which during revolution of the cylinder are brought into contact with the wire brushes for collecting the current. The diameter X Y is that on which these points of contact occur. The poles of the magnet are above and beneath this diameter.

In Frölich's system the farther end is crossed by the wires following its diameters. The remaining connections will be understood from Fig. 1056.

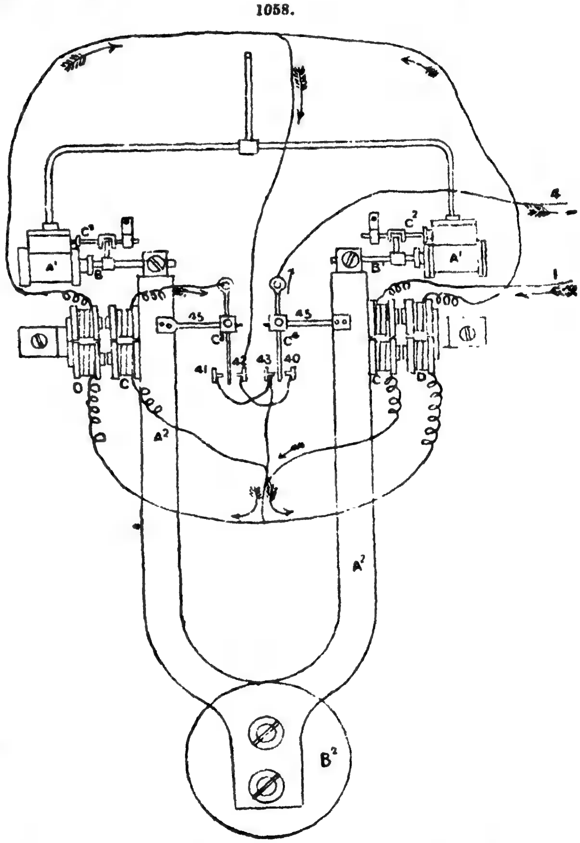
Breguet proposes two systems of winding, in which the wires crossing the farther end of the cylinder do not necessarily follow its diameter. One of these systems is shown in Fig. 1057, for which superiority to the preceding is claimed on the ground that less length of wire is required to produce the same results, and by this means the heat developed in the bobbin by the passage of the currents is reduced, the economic coefficient being proportionally raised.

The following table gives the four systems of winding in the order of increasing merit, the last being the best, and the numerical column indicates the length of inactive wire as a function of the radius of the ends of the cylinder. The length of effective wire is supposed to be the same in each case;—

Frölich's system	30·8
Alteneck's „	30·5
Breguet's „	26·0

Edison's machine, Fig. 1058, consists of a tuning-fork A^2, firmly attached to a stand B^2. This fork is of two prongs, but one only need be employed. The vibrating fork may be 2 yds. in length, and heavy in proportion. It has its regular rate of vibration, and the mechanism that keeps it in vibration is to move in harmony. A crank or revolving shaft may be employed, but it is preferable to use a small air, gas, or water engine, applied to each end of the fork. The cylinder A^1 contains a piston and a rod B^1, connected to the ends of the fork, and steam, gas, water, or other fluid under pressure acts within the cylinder, being admitted first to one side of the piston and then the other by a valve. The valve and directing rod C^2 are shown for this purpose. The fork A^2 may be a permanent magnet or an electro-magnet, or it is provided with permanent or electro-magnets. An electro-magnet, C, is shown on each prong of the fork, and opposed to these are the cores of the electro-magnets D. Hence, as the fork is vibrated, a current is set up in the helix of each electro-magnet D, in one direction as the cores approach each other, and in the opposite direction as they recede. This alternate current is available for electric lights, but if it is desired to convert the current into one of continuity in the same direction, a commutator is employed, operated by the vibrations of the fork to change the circuit connections in each vibration, and thereby make the pulsations continuous on the line of one polarity. A portion of the current thus generated may pass through the helices of the electro-magnets C, to intensify them to the maximum power, and the remainder of the current is employed for any desired electrical operation. The commutator springs or levers C^3 and C^4 are operated by rods 45. When the prongs of the fork are moving from each other, the contact of the levers C^3 C^4 will be with the screws 40, 41, and the current will be from line 1 through C to C, thence to C^3 and to 41, 43, and to the electro-magnets D D; from these by 42 to 40 C^4 and line, as shown by the arrows. When the prongs A^2 are vibrating towards each other, the circuit will be through C^3 C C^3 42, in the reverse direction through the circuit and magnets D D to 43 and by C^4 to line.

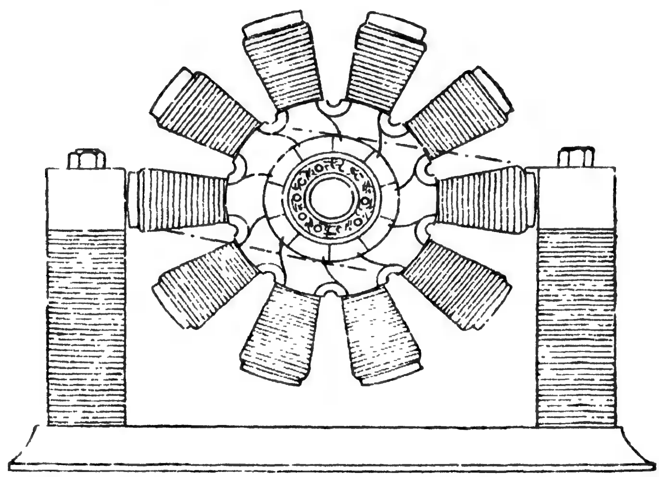
1058.



De Meriten's machine consists of a series of electro-magnets in the form of a wheel, the north pole of one following the south pole of the adjacent magnet. Each electro-magnet, when the wheel is at rest, stands with its poles beneath the poles of a horseshoe permanent magnet. These permanent magnets are set in a fixed frame around the periphery of the wheel of electro-magnets. The insulated wires on the coils of the armature of the machine are all wound in the same direction,

only the outer end of the wire of one coil is connected with the outer end of the wire of a coil next to it; whilst the inner end of the wire of the one coil communicates with the inner end of another coil next to it. The alternating currents produced are thus of the same sign throughout the whole ring. The two terminals of the wire on the ring, which constitute the two poles, communicate respectively with two copper rings fixed on the axis of the machine, and insulated from it. Two thick copper wires are in frictional contact with these rings, and are connected to terminal screws, from which the current is obtained. Multiple-circuit machines have been designed with the special purpose that the whole system of lighting should not be dependent upon the continuity of one circuit. This advantage necessitates a greater expenditure of motive power to produce the same light power.

Lontin introduced into England, in 1875, a plan for converting the whole of the electricity produced in the revolving armature of a machine, into the exciting magnets, instead of a portion. This had the effect of rendering the exciting magnets very powerful in a short time, and the magnetic resistance to the rotation of the coil increased in a few minutes to the extent that it was found difficult to overcome it. The circuit was then broken by an automatic commutator, and the special working circuit inserted. In 1876, Lontin constructed a machine to overcome the difficulty of the heat generated in the coils of the former machine. This latter consisted of an armature in the form of a wheel, with a central boss and spokes of soft iron, mounted on a shaft to which rotary motion could be imparted, Fig 1059. Each soft-iron spoke of the wheel has a coil of wire



wound on it, and is, in fact, an electro-magnet, which becomes a source of induced electricity when the wheel is revolved between the poles of a fixed electro-magnet. The residual magnetism of the cores of the electro-magnets is sufficient at first to generate a feeble current in the coils when the wheel is revolved; and a portion of this current, kept in one direction by a commutator, is diverted in the usual manner into the fixed electro-magnets, to intensify them.

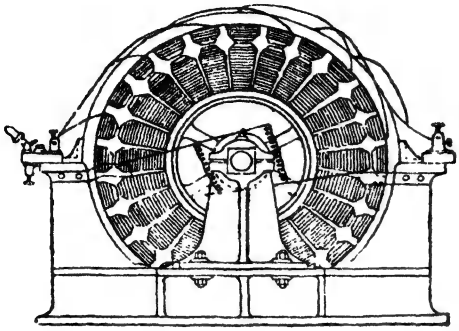
One or several of these induction wheels may be applied on the same shaft, placing them opposite one or more series of permanent or electro-magnets. When two wheels are fixed on the same shaft, one of them can supply currents exclusively for feeding the electro-magnets, and the currents from the other can be used for external work. If the currents are required to be of only one direction, a commutator or collector is employed, and one for each coil or pair of coils is placed on the shaft, to each being attached the two ends of the wire of the corresponding coil or pair of coils. When merely collectors are used, all the coils on the wheel are connected up in series, so as to form a completely closed circuit as in Fig. 1059. All the coils approaching a pole of the electro-magnet are inversely electrified to those receding from the same pole. A metal strip is arranged opposite the pole of the electro-magnet, to collect, by contact, the electricity generated in the coil at the instant that its polarity becomes reversed; a similar rubber is also applied opposite the other pole of the electro-magnet. In order to avoid oxidizing effect under the action of sparks, the commutators are enclosed in a bath of non-drying oil.

Lontin's greatest improvement is the construction of dynamo-electric machines with inducing electro-magnets having a rotary motion, whilst the induced coils are stationary. Figs. 1060 and 1061 are of this machine. The coils of the induction wheel are in this case the inducers, and are transformed into electro-magnets by the current of a spare magneto-electric machine passed through them. On rotation of the wheel they induce in the surrounding coils a series of currents, which can be utilized, without the use of collector or contact-ring. A machine having 50 induced coils, would have 50 sources of electricity that could be employed either separately or combined.

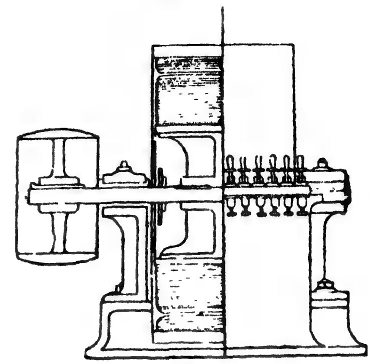
The fixed electro-magnet shown in Fig. 1059 may have its cores prolonged, so that more than one coil of insulated wire can be placed upon them. Thus, when the wheel is turned into an inducer, by reason of the currents already induced in it by the electro-magnets, it will in its turn induce currents in the additional coils, and these currents can be utilized for electric lighting. Figs. 1060 and 1061 are of a machine employed as a generator to supply currents to the dividing machine, Fig. 1062.

The dividing machine consists of a revolving drum carrying a series of radial magnets. The coils of these radial magnets are connected together, so that one magnet has its positive pole at the outside end, and the succeeding magnet its positive pole at the inside end. The radial magnets are thus made to alternate their poles considered as a circumference to the wheel. By this arrangement the revolving wheel induces a number of alternate currents, equal to half the number

1060.



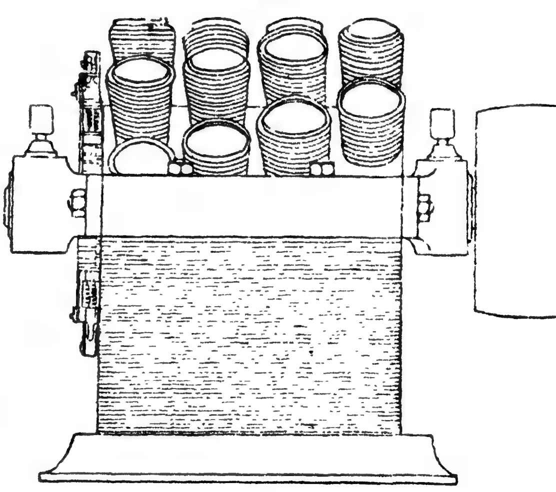
1061.



of spokes. An exterior commutator, which may be connected up in many different ways, enables these currents to be combined as required. This duplex Lontin system gives a total illuminating power of 12,000 candles. The generating machine is driven at 250 revolutions, and the distributing or dividing machine at 400 a minute. With an engine of 8 horse-power nominal, 12 light-circuits can be maintained.

The Gramme distributor, Figs. 1063 and 1064, consists of a ring of iron wound with coils of insulated copper wire, alternately right and left handed, the wire being coiled in one direction, so as to cover one-eighth part of the ring, then in the opposite direction for the next eighth part, each of the eight sections of the ring being wound in the reverse direction to the winding of the two adjacent sections. This ring may be considered as eight curved electro-magnets placed end to end, with their similar poles in contact, so as to form a circle. It is rigidly fixed in a vertical position to the solid framing of the apparatus, the inducing electro-magnets revolving within it.

1062.

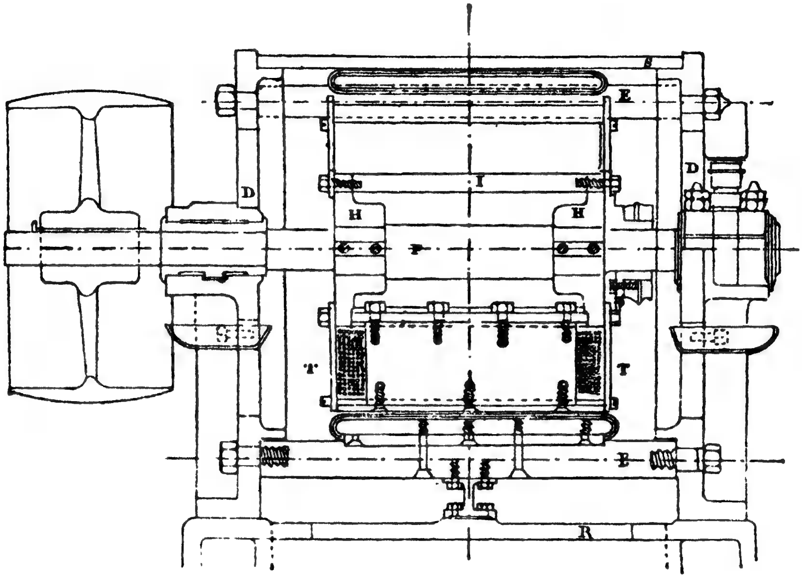


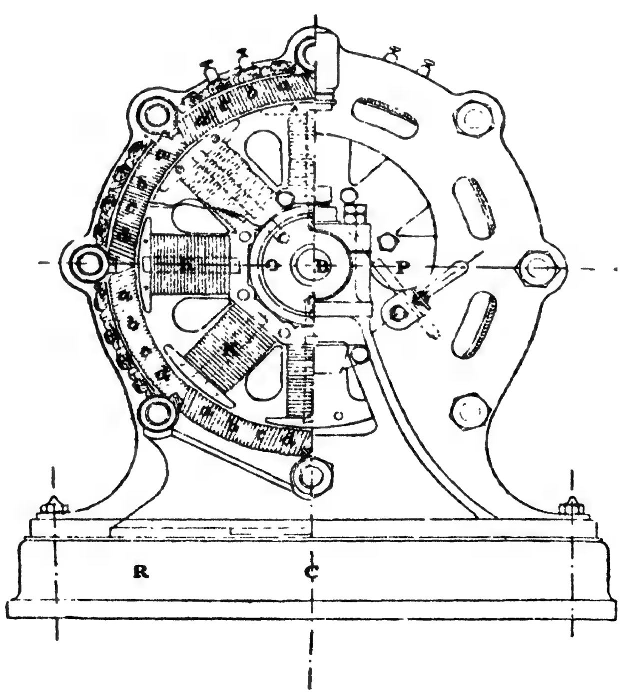
There are eight electro-magnets fixed radially to a central boss revolving upon a horizontal shaft, upon which is a pulley, driven by a band from a motor. These radial flat electro-magnets are wound alternately right and left handed, and their alternate ends are consequently of opposite polarity. The cores of these magnets are extended by plates to increase the area of the magnetic field by which currents are induced in the coils of the ring.

There is no self-contained apparatus for producing the current by which the electro-magnets are magnetized, but a small Gramme machine of the continuous current type is employed, and is driven by a separate strap. The current from this machine is caused to circulate in the coils of the rotating radial electro-magnets, by which these are magnetized to saturation. Each section of the ring is built up of four subsections, *a b c d*, Fig. 1064, and all these subsections of any one section are wound in the same direction. This subdivision admits of the connecting-up of the subsections into 32, 16, 8 or 4 circuits. All the subsections marked *a* are influenced by the rotating magnets in precisely similar manner, because the influence of a north pole upon a coil wound in a right-handed direction is the same as that of a south pole upon a coil wound in a left-handed direction. Similarly, the currents in all the *b* coils are of one direction, whatever the position of the rotating magnets. Thus, all the coils similarly marked can be connected into one circuit, and terminal screws are provided for the required arrangement. The current from the small machine is led to the rotating magnets through the flat brushes of silvered copper wire attached to the framework of the machine, and in rubbing contact with two insulated copper cylinders, one connected to each end of the magnet circuit.

A largest sized machine supplies 16 Jablochkoff candles, each of 1000 candle-power, at a speed of 600 revolutions a minute, absorbing 16 horse-power.

On the mechanical efficiency of dynamo-electro machines, Paget Higgs states, there can be nothing done in the inter-comparison of any natural force until accurate measurements have been





made. For these measurements the electrical engineer has mainly to look to the labours of the committee on dynamo-electric machines formed by the Franklin Institute, and to Houston and Thomson's report as to the ratio of efficiency in the conversion of motive power into electricity.

In entering this comparatively new field of research, peculiar difficulties occurred, owing to conditions that do not exist in the various forms of batteries used as sources of electrical power. In many battery circuits a high external resistance may be employed, and the electro-motive force remains comparatively constant, while in dynamo-electric machines, in which the reaction principle is employed, the introduction of a very high external resistance into the circuit must be necessarily attended by decided variations in the electro-motive force, due to changes in the intensity of the magnetic field in which the currents have their origin. Moreover, a considerable difficulty is experienced in the great variations in the behaviour of those machines when the resistance of the arc, or that of the external work, is changed. Changes, due to loss of conductivity by heating, also take place in the machine itself.

These variations are also attended by changes in the power required to drive the engine, and in the speed of running, which again react on the current generated.

There are certain normal conditions in the running of dynamo-electric machines designed for lighting, under which all measurements must be made, viz.;—

The circuit must be closed, since on opening, all electrical manifestations cease.

The circuit must be closed through an external resistance equal to that of the arc of the machine.

The arc taken as the standard must be the normal arc of the machine. This condition can only be fulfilled by noticing the behaviour of the machine, while running, as to the absence of sparks at the commutator, the heating of the machine, the regularity of action in the consumption of carbons in the lamp, &c.

The speed of the machine must be, as nearly as possible, constant.

The power required to maintain a given rate of speed must be, as nearly as possible constant.

The machines submitted to the committee of the Franklin Institute for determination were as follows;—

Two machines of different size, and of somewhat different detailed construction, built according to the invention of C. F. Brush, and styled respectively in the report as A^1, the larger of the two machines, and A^2, the smaller.

Two machines known as the Wallace-Farmer machines, differing in size, and in minor details of construction, and designated respectively as B^1, the larger of the two, and B^2, the smaller. In the case of the machine B^1, the experiments were discontinued after the measurement of the resistances was made, insufficient power being at disposal to maintain the machine at its proper rate of speed.

A Gramme machine of the ordinary construction.

All the above machines are constructed so that the whole current traverses the coils of the field magnets, being single current machines, in which the reaction principle is employed. In the case of the machine designated A^2, the commutators are so arranged as to permit the use of two separate circuits when desired.

For the purpose of preserving a ready measure of the current produced by each machine, under normal conditions, a shunt was constructed, by which an inconsiderable but definite proportion of the current was caused to traverse the coils of a galvanometer, thus giving with each machine a convenient deflection, which could at any time be reproduced. As the interposition of this shunt in the circuit did not appreciably increase its resistance, the normal conditions of running were preserved.

As indicating the preservation of normal conditions in any case, the speed of running and the resistances being the same as in any previous run, it was found that when there was an equal expenditure of power, as indicated by the dynamometer, the current produced, as indicated by the galvanometer, was in each case the same.

Certain of the machines experimented with, heated considerably on a long run; most of the tests, therefore, were made when the machines were as nearly as possible at about the temperature of the surrounding air. It is evident that no other standard could be well adopted, as under a prolonged run the temperature of the different parts of the machine would increase very unequally; and, moreover, it would be impossible to make any reliable measurements of the temperatures of many such parts.

In measuring the resistance of the machines, a Wheatstone's bridge, with a sliding contact, was used, in connection with a delicate galvanometer and a suitable voltaic battery. In taking the resistances of the machines, several measurements were made with the armatures in different positions, and the mean of these measurements taken as the true resistance.

It was, of course, a matter of the greatest importance to obtain a value for the resistance of the arc in any case, since upon the relative values of this resistance, and that of the machine, the efficiency would in any given case to a great extent depend. In each case, the arc of which the resistance was to be taken, was that which was obtained when each machine was giving its average results as to steadiness of light and constancy of the galvanometer deflection.

The method adopted for the measurement of the arc was that of substitution, in which a resistance of German silver wire, immersed in water, was substituted for the arc, without altering any of the conditions of running. This substituted resistance was afterwards measured in the usual way, and gave, of course, the resistance of the arc. It could, therefore, when so desired, serve as a substitute for the arc. No other method of obtaining the arc resistance appeared applicable, since the constancy of the resistance of the arc required the passage of the entire current through the carbons.

It may be mentioned, as an interesting fact in this connection, that when the current flowing was great, the arc corresponding thereto had a much lower resistance than when the current was small. This fact is, of course, due to increased vaporization, consequent on increased temperature in the arc.

In determining the true arc resistance, the resistance of the electric lamp controlling the arc

was measured separately, and deducted from the result obtained with the German silver wire substitute.

For ease of obtaining a resistance of German silver wire equal in any case to that of the arc, a simple rheostat was constructed, by winding, upon an open frame, such a length of wire as was judged to be in excess of the resistances of any of the arcs to be measured. By means of a sliding contact, successive lengths of the wire were added until the conditions were reproduced. With this arrangement, no difficulty was experienced in reproducing the same conditions of normal running as when the arc was used. The same conducting wires were used throughout these experiments. Being of heavy copper, their resistance was low, about ·016 ohm.

To determine the value of the current, two methods were selected, one based on the production of heat in a circuit of known resistance, and the other upon the comparison of a definite proportion of the current with that of a Daniell's battery.

In the application of the first method, eight litres of water, at a known temperature, were taken, and placed in a suitable non-conducting vessel. In this was immersed the German silver wire, and the sliding contact adjusted to afford a resistance equal to that of the normal arc of the machine under consideration. This was now introduced into the circuit of the machine. All these arrangements having been made, the temperature of the water was accurately obtained by a delicate thermometer. The current from the machine running under normal conditions was allowed to pass, for a definite time, through the calorimeter so provided. From the data thus obtained, after making the necessary corrections as to the weight of the water employed, the total heating effect in the arc and the lamp, as given in Table II., was deduced.

Since the heat in various portions of an electrical circuit is directly proportional to the resistance of those portions, the total heat of the circuit was easily calculated, and is given in Table III., in English heat-units. For ease of reference, the constant has been given for conversion of these units into the metrical units of heat.

Having thus obtained the heating effect, the electrical current is—

$$C = \sqrt{\frac{W\,h \times 772}{R\,t\,c}},$$

where C = the Weber current an ohm, W the weight of water in pounds, h the increase of temperature in degrees F., 772 Joule's constant, R the resistance in ohms, t the time in seconds, and c the constant, ·737335, the equivalent in foot-pounds of one weber an ohm a second. The currents so deduced for the different machines are given in Table VI.

The other method employed for obtaining the current, the comparison of a definite portion thereof with the current from a Daniell's battery, was as follows;—A shunt was constructed, of which one division of the circuit was ·12 ohm, and the other 3000 ohms. In this latter division of the circuit was placed a low-resistance galvanometer, on which convenient deflections were obtained. This shunt being placed in the circuit of the machine, the galvanometer deflections were carefully noted. To the resistance afforded by the shunt, such additional resistance was added, as to make the whole equal to that of the normal arc of the machine. These substituted resistances were immersed in water, in order to maintain an equable temperature.

Three Daniell's cells were carefully set up and put in circuit with the same galvanometer, and with a set of standard resistance coils. Resistances were unplugged sufficient to produce the same deflections as those noted with the shunt above mentioned. The shunt ratio, as nearly as could conveniently be obtained, was $\frac{1}{25000}$. Then the formula

$$C = \frac{s\,n \times 1{\cdot}079}{R},$$

where C equals the Weber current, s the reciprocal of the shunt ratio, n the number of cells employed, 1·079 the assumed normal value of the electro-motive force of a Daniell's cell, and R the resistances in the circuit with the battery, gives at once the current. In comparison with the total resistances of the circuit, the internal resistance of the battery was so small as to be neglected.

The results obtained, Table II., were as follows;—

TABLE II.—COMPARISON OF RESISTANCES.

Name of Machine.	Shunt Ratio.	No. of Daniell's Cells.	Resistances Unplugged.	Speed of Machine.
			ohms.	rev.
Large Brush	$\frac{1}{25000}$	3	2710	1340
Small „	„	„	3700	1400
Wallace-Farmer	„	„	8320	844
	„	„	6980	1044
Gramme	„	„	4800	800

The Weber currents, as calculated from the above data, are given in Table VI.

From the results thus derived, the electro-motive force was deduced from the general formula—

$$E = C \times R.$$

The electro-motive force thus calculated will be found in Table VI.

Statements are frequently made, when speaking of certain dynamo-electric machines, that they are equal to a given number of Daniell's or other well-known battery cells. It is evident, however, that no such comparison can properly be made, since the electro-motive force of a dynamo-electric

machine, in which the reaction principle is employed, changes considerably with any change in the relative resistances of the circuit of which it forms a part, while that of any good form of battery, disregarding polarization, remains approximately constant. The internal resistance of dynamo-electric machines is, as a rule, very much lower than that of any ordinary series of battery cells, as generally constructed, and, therefore, to obtain with a battery conditions equivalent to those in a dynamo-electric machine, a sufficient number of cells in series would have to be employed to give the same electro-motive force; while, at the same time, the size of the cells, or their number in multiple arc, would require to be such that the internal resistance should equal that of the machine.

Suppose, for example, that it be desired to replace the large Brush machine by a battery whose electro-motive force and internal and external resistances are all equal to that of the machine, and that as a standard a Daniell's cell of an internal resistance, say, of one ohm is adopted. Referring to Table VI., the electro-motive force of this machine is about 39 volts, to produce which about 37 cells, in series, would be required; but by Table IV., the internal resistance of this machine is about ·49 ohm. To reduce the resistance of our standard cell to this figure, when 37 cells are employed in series, 76 cells, in multiple arc, would be required. Therefore, the total number of cells necessary to replace this machine would equal 37 × 76, or 2812 cells, working over the same external resistance. It must be borne in mind, however, that although the machine is equal to 2812 of the cells taken, no other arrangement of these cells than that mentioned, namely, 76 in multiple arc and 37 in series, could reproduce the same conditions, and, moreover, the external resistances must be the same. The same principles, applied to other machines, would, when the internal resistance was great, require a large number of cells, but arranged in such a way as to be extremely wasteful, from by far the greater portion of the work being done in overcoming the resistance of the battery itself. The true comparative measure of the efficiency of dynamo-electric machines, as means for converting motive power into work derived from electrical currents, whether as light, heat, or chemical decomposition, is found by comparing the units of work consumed with the equivalent units of work appearing in the circuit external to the machine. In Table V. the comparative data are given. In the first column the dynamometer reading gives the total power consumed, from which are to be deduced the figures given in the second column, being the work expended in friction, and in overcoming the resistance of the air; although, of course, it must be borne in mind that that machine is the most economical in which, other things being equal, the resistance of the air and the friction are the least. The third column gives the total power expended in producing electrical effects, a portion only of which, however, appears in the effective circuit, the remainder being variously consumed in the production of local circuits in the different masses of metal composing the machines. This work eventually appears as heat in the machine. Columns four, five, and six give respectively the relative amounts of power variously appearing as heat in the arc, in the entire circuit, and as heat due to local circuits in the conducting masses of metal in the machine, irrespective of the wire. This latter consumption of force may be conveniently described as due to the local action of the machine, and is manifestly comparable to the well-known local action of the voltaic battery, since in each case it not only acts to diminish the effective current produced, but also adds to the cost.

No determination made with an unknown or abnormal external resistance can be of any value, since the proportion of work done, in the several portions of an electrical circuit, depends upon, and varies with, the resistances they offer to its passage. If, therefore, in separate determinations with any particular machine, the resistance of that part of a circuit of which the work is measured be in one instance large in proportion to the remainder of the circuit, and in another small, the two measurements thus made would give widely different results, since in the case where a large resistance was interposed in this part of the circuit, the percentage of the total work appearing there would be greater than if the small resistance had been used.

When an attempt has been made to determine the efficiency of a single machine, or of the relative efficiency of a number of machines, by noting the quantity of gas evolved in a voltameter, or by the electrolysis of copper sulphate in a decomposing cell, when the resistance of the voltameter or decomposing cell did not represent the normal working resistance, it is manifest that the results cannot properly be taken as a measure of the actual efficiency.

In Table IV. it will be found that, in general, where the machine used had a high internal resistance, the arc resistance normal to it was very high, but they are not necessarily dependent upon each other. The arc resistance depends on the intensity of the current, the nature of the carbons, and on the distance apart. Other conditions being the same, the resistance of the arc is less when the current is great.

Since all the machines examined were built for lighting, it will readily be seen that, other things being equal, that machine is the most economical in which the work done in the arc bears a considerable proportion to that done in the whole circuit, and since, with any given current, the work is proportional to the resistance, we have in Table IV. the data for comparison in this regard. For example, in the second determination of A^1, the large Brush machine, the resistance of the arc constitutes considerably more than one-half the total resistance of the entire circuit, while in B^2, the small Wallace-Farmer machine, it constitutes somewhat more than one-third the total resistance. These relative resistances give, of course, only the proportion of the current generated, which is utilized in the arc as light and heat, the conditions of power consumed to produce the current not being there expressed.

During any continued run, the heating of the wire of the machine, either directly by the current, or indirectly from conduction from those parts of the machine heated by local action, as explained in a former part of this report, produced an increased resistance, and a consequent falling off in the effective current. Thus in Table IV., at the temperature of 73·5° F., A^1, the large Brush machine, had a resistance of ·485 ohm, while at 88° F., at the armature coils, it was ·495 ohm. These differences were still more marked in the case of B^1.

In A^2, the small Brush machine, it will be noticed that two separate values are given for the resistance of the machine. These correspond to different connections, the resistance, 1·239 ohm, being the connection at the commutator for low resistance, the double connecting wires being coupled in multiple arc, while 5·044 ohms represent the resistance when the sections of the double conductor are coupled at the commutator in series.

TABLE III.—SHOWING WEIGHT, POWER ABSORBED, LIGHT PRODUCED, &c., BY DYNAMO-ELECTRIC MACHINES, tested by a Committee of the Franklin Institute, 1877–78.

Name of Machine.	Weight in Pounds.	Copper Wire in Armature. Size.	Copper Wire in Armature. Weight.	Copper Wire in Field Magnets. Size.	Copper Wire in Field Magnets. Weight.	Revolutions of Armature a Minute.	Foot-pounds of Power Consumed.	Horse-power.	Light produced in Standard Candles. Total.	Light produced in Standard Candles. Each H.-P.	Foot-pounds of Power Consumed each Candle-light.	Size of Carbons.	Length of Carbon Consumed an hour. +	Length of Carbon Consumed an hour. −
		in.	lb.	in.	lb.									
Large Brush ..	475	·081	32	·134	100	1340	107·603	3·26	1230	377	87·4	$\frac{3}{8}\times\frac{3}{8}$	1·78	·34
Small „ ..	390	·063	24	·096	80	1400	124·248	3·76	900	339	137·	$\frac{3}{8}\times\frac{3}{8}$	1·91	·58
Large Wallace	600	·042	50	·114	125	800	..	..	823	..	..	..	..	..
Small „ ..	350	·043	18¾	·098	41	1000	128·544	3·89	440	113	292·	$\frac{1}{4}\times\frac{1}{4}$	2·45	·073
Gramme	366	·059	104	·108	104	800	60·992	1·84	705	383	85·	$\frac{1}{4}\times\frac{1}{4}$	3·15	·55

TABLE IV.—RESISTANCES OF DYNAMO-ELECTRIC MACHINES.

Name of Machine.	Temperature in Degrees F.	Resistances. Of Machine + Conductor.	Resistances. Of Arc + Lamp.	Resistance of Conducting Wire.	Resistance of Lamp exclusive of Arc.	Corrected Resistances. Of Machine − Conductor.	Corrected Resistances. Of Arc − Lamp.	Total Resistance of the Circuit, Ohms.	Remarks.
A^1. Large Brush ..	73½	·485	·57	·016	·032	·483	·54	1·055	At beginning of run.
A^1. „ „ ..	88	·495	·82	·016	·032	·493	·79	1·315	After running 25 minutes.
A^2. Small „ ..	74	1·255	1·70	·016	·032	1·239	1·67	2·955	Arranged for low resistance.
A^2. „ „ ..	74	5·06	..	·016	..	5·044	..	..	„ high „
B^1. Large Wallace	74	4·60	1·98	·016	·032	4·584	1·95	6·58	Machine cold.
B^2. „ „ ..	118	5·13	..	·016	..	..	..	..	After 40 minutes' run.
B^2. Small „ ..	74	4·96	2·87	·016	·1025	4·944	2·77	7·83	At 844 revolutions.
B^2. „ „ ..	74	4·96	3·24	·016	·1025	4·944	3·18	8·24	At 1000 „
Gramme	68	1·685	1·35	·016	·1025	1·667	1·25	3·04	Arc not normal.
„	68	1·685	1·97	·016	·1025	1·667	1·87	3·66	Arc normal.

TABLE V.—THERMIC EFFECTS OF DYNAMO-ELECTRIC MACHINES.

Name of Machine.		Heating Effect in Arc and Lamp.			ce of ...ter, Arc.	...rc an ...1 Lb., Fahr	...t of ... in Lb.			
A^1. Large Brush ..	51½	18·64	23·25	10	·82	43·338	69·49	·881	1340	107606
A^2. Small „ ..	34	18·63	9·09	5	1·70	33·87	58·87	·332	1200	117700
A^2. „ „ ..	37	18·63	18·66	8	1·70	43·45	75·57	·426	1400	124248
B^2. „ Wallace ..	25½	18·63	11·50	12	2·87	17·85	48·70	·104	844	97068
B^2. „ „ ..	55½	18·63	4·92	6	2·87	15·28	41·69	·089	844	97068
B^2. „ „ ..	24½	18·64	10·75	10	3·28	20·04	50·34	·102	1040	128544
Gramme	38	18·64	16·25	10	1·97	30·29	56·28	·256	800	60992

For conversion to metrical heat units, 1 lb. water, 1° F. = 259·185 grammes of water, 1° C.

Referring to Table V., the numbers given in the column headed, Heat in arc and lamp, are the measure of the total heating power in that portion of the circuit external to the machine. They do not, however, in the case of any machine, represent the energy which is available for the production of light, which depends also on the nature and the amount of the resistance over which it is expended.

For example, the heat in arc and lamp are practically the same in each of the Brush machines, if the measurement of the smaller of these machines be taken at the higher speed. The amount of light produced, however, is not the same in these two instances, being considerably greater in the case of the larger machine.

The explanation of this apparent anomaly is undoubtedly to be found in the different resistances of the arcs in the two cases. In the large Brush machine the carbons are nearer together than when the small machine is used. This suggests the very plausible explanation, that the cause of the difference is to be attributed to the fact that although the total heating effect is equal in each case, when the large machine is used, the heat produced is evolved in a smaller space, and its temperature, and consequent light-giving power, thereby largely increased.

It would seem, indeed, that any future improvements made in the direction of obtaining an increased intensity of light from a given current, will be by concentrating the resistance normal to the arc in the most limited space practicable, thereby increasing the intensity of the heat, and, consequently, its attendant light.

It may be noted in this connection, that in all the cases in which the resistance of the arc was low, the photometric intensity was high. This, indeed, might naturally be expected, since a great intensity of heat would, under existing conditions of the use of the arc, admit of increased vaporization, and consequent lowering of the resistance.

In the column headed, Total heat of circuit, are given the quantities of heat developed in the whole circuit, which numbers, compared with those in the preceding column, furnish us with the relative proportions of the work of the circuit which appear in the arc and lamp.

The column headed, Heat each ohm a second, gives the relative work an ohm of resistance in each case, and these numbers, multiplied by the total resistance, give the total energy of the current expressed in heat units a second.

In Table VI. are given the results of calculation and measurement, as to the electrical work of each machine.

It is evident, to those acquainted with the principles of electrical science, that the Weber current and the electro-motive force, are the data for comparing the work of these machines with that of any other machine or battery, whether used for light, heat, electrolysis, or any other form of electrical work.

As might be supposed, the values given in Table VI., of the Weber current, approximate relatively to the photometric values, as will be seen from an examination of that part of the general report of the committee relating to photometric measurements.

The values of the Weber current, as deduced from the heat developed, and from the comparison with a Daniell's cell, do not exactly agree; nor could this have been expected, when the difficulty of minutely reproducing the conditions as to speed and resistance is considered.

By comparison of the electro-motive force of the different machines, it appears that no definite unit seems to have been aimed at by all the makers as that best adapted to the production of light.

Table VI.—Current and Electro-Motive Force of Dynamo-Electric Machines.

Name of Machine.	Weber Current each Ohm a Second. From Heat developed.	Weber Current each Ohm a Second. By Comparison with Daniell's Battery.	Electro-motive Force in Volts. Calculated from Heat and Resistances.	Electro-motive Force in Volts. By Comparison with Daniell's Battery.	Per cent. of the Work of Current appearing in the Arc.	Corresponding Dynamometric Values.	Remarks.	
								Rev.
A[1]. Large Brush	30·37	29·87	39·94	39·28	60·08	107606	Speed,	1340
A[2]. Small „ ..	18·63	..	55·05	..	..	117700	„	1200
A[2]. „ „ ..	21·12	21·87	62·41	64·43	56·51	124248	„	1400
B[2]. Small Wallace	10·42	9·73	81·59	76·19	35·38	96068	„	844
B[2]. „ „	9·64	..	75·48	..	..	..	„	844
B[2]. „ „	10·33	11·16	85·12	91·96	38·59	128544	„	1040
Gramme	16·38	16·86	59·95	61·71	51·09	60992	„	800

Table VII.—Effects of Dynamo-Electric Machines in Foot-Pounds a Minute.

Name of Machine.	Dynamometer Reading, Foot-lb. Consumed.	Friction and Resistance of Air.	Foot-lb. Consumed after Deducting Friction.	Foot-lb. appearing in Arc as Heat.	Foot-lb. appearing in whole Circuit.	Foot-lb. unaccounted for in the Circuit.	Per cent. of Power utilized in Arc.	Per cent. of Effect after Deducting Friction.
A[1]. Large Brush	107,606	17,950	89,656	33,457	53,646	36,010	31	37½
A[2]. Small „ ..	117,700	12,328	105,372	26,148	45,448	59,924	22	25
A[2]. „ „ ..	124,248	14,976	109,272	33,543	58,340	50,932	27	31
B[2]. Small Wallace	97,068	7,800	89,268	13,780	37,596	51,672	14	15½
B[2]. „ „	128,544	11,072	117,472	15,469	38,862	78,610	12	13
Gramme	60,992	4,512	56,480	23,384	43,448	13,032	38	41

For conversion into Gramme-metres, 1 foot-pound = 138 Gramme-metres, nearly.

Table VII. is designed especially to permit a legitimate comparison of the relative efficiency of the machines, as well as their actual efficiency in converting motive power into current. The actual dynamometer reading is given in the first column. On account of differences of construction and

differences in speed of running, the friction and resistance of the air vary greatly, being least with the Gramme, as might be expected, since the form of the revolving armature, and the speed of the machine conduce to this result. This is, of course, a point greatly in favour of the Gramme machine.

That part of the power expended available for producing current is given in the third column, being the remainder, after deducting the friction, as above mentioned; but this power is not in any case fully utilized in the normal circuit. This is found to be the case by comparing calculations of the total work of the circuit in foot-pounds, as given in the appropriate column, with the amount expended in producing such circuit.

For instance, in the case of A^1, the large Brush machine, the available force for producing current is 89,656 foot-pounds a minute, of which only 53,646 reappear as heat in the circuit. The balance is most probably expended in the production of local currents in the various conducting masses of metal composing the machine. The amount thus expended in local action is given in the column designated, Foot-lb. unaccounted for in the circuit. A comparison of the figures in this column is decidedly in favour of the Gramme machine, it requiring the smallest proportion of power expended to be lost in local action. When, however, we consider that the current produced by the large Brush machine is nearly double that produced by the Gramme, the disproportion in the local action is not so great.

The columns containing the percentages of power utilized in the arc, and useful effect after deducting friction, need no special comment.

The determinations made enabled the following opinions to be formed as to the comparative merits of the machines submitted for examination ;—

The Gramme machine is the most economical, considered as a means for converting motive power into electrical current, giving in the arc a useful result equal to 38 per cent., or to 41 per cent. after deducting friction and the resistance of the air. In this machine the loss of power in friction and local action is the least, the speed being comparatively low. If the resistance of the arc is kept normal, very little heating of the machine results, and there is an almost entire absence of sparks at the commutator.

The large Brush machine comes next in order of efficiency, giving in the arc a useful effect equal to 31 per cent. of the total power used, or 37½ per cent. after deducting friction. This machine is, indeed, but little inferior in this respect to the Gramme, having, however, the disadvantages of high speed, and a greater proportionate loss of power in friction, &c. This loss is nearly compensated by the advantage this machine possesses over the others of working with a high external, compared with the internal, resistance, this also ensuring comparative absence of heating in the machine. This machine gave the most powerful current, and consequently the greatest light.

The small Brush machine stands third in efficiency, giving in the arc a useful result equal to 27 per cent., or 31 per cent. after deducting friction. Although somewhat inferior to the Gramme, it is, nevertheless, a machine admirably adapted to the production of intense currents, and has the advantage of being made to furnish currents of widely varying electro-motive force. By suitably connecting the machine, as before described, the electro-motive force may be increased to over 120 volts. It possesses, moreover, the advantage of division of the conductor into two circuits, a feature which, however, is also possessed by some forms of other machines. The simplicity and ease of repair of the commutator are also advantages. Again, this machine does not heat greatly.

The Wallace-Farmer machine does not return to the effective circuit as large a proportion of power as the other machines, although it uses, in electrical work, a large amount of power in a small space. The cause of its small economy is the expenditure of a large proportion of the power in the production of local action. By remedying this defect, a very admirable machine would be produced. After careful consideration of all the facts, the committee unanimously concluded that the small Brush machine, though somewhat less economical than the Gramme machine, or the large Brush machine, for the general production of light and of electrical currents, was, of the various machines experimented with, the best adapted for the purposes of the Institute, chiefly for the following reasons;—It is adapted to the production of currents of widely varying electro-motive force, and produces a good light. From the mechanical details of its construction, especially at the commutators, it possesses great ease of repair to the parts subject to wear.

In order to make the measurements as accurate as possible, it was found necessary so to arrange the photometric apparatus that no reflected or diffused light should fall on the photometer, and thus introduce an element of error. The electric lamp was enclosed in a box, open at the back for convenience of access, but closed with a non-reflecting and opaque screen during the experiments. Projecting from a hole in the front of the box was a wooden tube, 6 in. square inside and 8 ft. long, with its inner surface blackened to prevent reflection, thus allowing only a small beam of direct light to leave the box. This beam of light passed into a similar wooden tube, placed at a proper distance from the first, and holding in its farther end the standard candle. This tube also held the da·k box of a Bunsen photometer, mounted on a slide, so as to be easily adjusted at the proper distance between the two sources of light. A slit in the side of the tube enabled the observer to see the diaphragm. The outer end of the second tube was also covered with a non-reflecting hood, and the room was of course darkened when photometric measurements were taken. The rigid exclusion of all reflected or diffused light is the only trustworthy method of obtaining true results, and will, no doubt, account in a large measure for the lower candle-power obtained by these experiments than that obtained by many previous experimenters.

The difficulties encountered in the measurement of the light arising from the difference in colour, were at first thought to be considerable, but further practice and experience enabled the observer to overcome them to such an extent that the error arising from this cause is inconsiderable, being greatly less than that due to the fluctuations of the electric arc.

In determining the amount of light produced by each machine, it was run continuously for from four to five hours, and observations made at intervals, care being taken to maintain the speed and other conditions normal. One of the most important conditions necessary to ensure correct

results was the relative position of the carbon points. Great care was taken that the axes of the two sticks or pencils of carbon were in the same line, so that the light produced should be projected equally in all directions. Were the axes of the carbon pencils not in the same line, a much greater quantity of light would be projected in one direction, and the result of calculation of the light produced, based on the inverse square of the distance from the photometer, would be too great or too small, according as this adjustment was in the one or the other direction.

Experiments were made to determine what effect on the amount of light was produced by so adjusting the carbons that the front edge of the upper one was in line with the centre of the lower one.

Front	2218 candles
Side	578 „
„	578 „
Back	111 „
	3485 ÷ 4 = 871.

The light produced by the same machine, under the same conditions, except the carbons being adjusted in one vertical line, was 525 candles. This would seem to indicate that nearly 66 per cent. more light was produced by this adjustment of the two carbons; but a close study of the conditions proves that such is not the case, and that there is no advantage to be derived from such adjustment, except when the light is intended to be used in one direction only.

The following is a statement upon this point, in the report of N. Douglass, Engineer to the Trinity House;—

I have found this arrangement of the carbons, the axis of the bottom carbon nearly in the same vertical plane as the front of the top carbon, and assuming the intensity of the light with the carbons having their axes in the same vertical line to be represented by 100, the intensity of the light in four directions in azimuth, say E., W., N., and S., will be nearly as follows;—

East or front intensity	287 to 100
North or side „	116 „ 100
South „ „	115 „ 100
West or back „	38 „ 100
	557 ÷ 4 = 139 to 100.

In measuring the candle-power of the light produced by each machine, I have given the mean intensity obtained in the direction of the photometer, the carbons in lamp working with the Holmes and Alliance machines, being always arranged with the axes in the same vertical line, and the carbons in the lamp working the Gramme and Siemens' machine being always arranged with the front edge of the top carbon nearly on the centre of the bottom carbon.

It is, therefore, evident that the results given by Douglass must be divided by 2·87 in making a comparison with those obtained by the Franklin Institute Committee.

The following abstract, Table VIII., from a report of J. Tyndall, addressed to the Trinity Board, upon experiments carried out to ascertain the relative values of different apparatus, completes the list as regards other machines than the preceding.

The machines experimented on were the following;—

Holmes' machines, which have been already established for some years at the South Foreland Lighthouse. Gramme's machine. Two Gramme's machines coupled together. Siemens' large machine. Siemens' medium machine.

TABLE VIII.—COST, DIMENSIONS, WEIGHT, HORSE-POWER ABSORBED, AND LIGHT PRODUCED BY THE DYNAMO-ELECTRIC MACHINES, tried at the South Foreland, 1876–77.

Names of Machines.	Dimensions.			Weights.	Horse-power Absorbed.	Revolutions a Min.	Light produced, in Standard Candles.		Light produced each Horse-power in Standard Candles.		Size of Carbons.
	Length.	Breadth.	Height.				Condensed Beam.	Diffused Beam.	Condensed Beam.	Diffused Beam.	
	ft. in.	ft. in.	ft. in.	tons cwt. qr. lb.							
Holmes	4 11	4 4	5 2	2 11 1 7	3·2	400	1,523	1,523	476	476	$\frac{3}{8}$ by $\frac{3}{8}$
Alliance	4 4	4 6	4 10	1 16 1 21	3·6	400	1,953	1,953	543	543	$\frac{3}{8}$ „ $\frac{3}{8}$
Gramme, No. 1	2 7	2 7	4 1	1 5 2 0	5·3	420	6,663	4,016	1,257	758	$\frac{1}{2}$ „ $\frac{1}{2}$
„ „ 2	2 7	2 7	4 1	1 5 2 0	5·74	420	6,663	4,016	1,257	758	$\frac{1}{2}$ „ $\frac{1}{2}$
Siemens, large ..	3 9	2 5	1 2	0 11 2 18	9·8	480	14,818	8,932	1,512	911	$\frac{11}{16}$ „ $\frac{11}{16}$
„ small—No. 58	2 2	2 5	0 10	0 3 3 0	3·5	850	5,539	3,339	1,582	954	$\frac{1}{2}$ „ $\frac{1}{2}$
„ 68	2 2	2 5	0 10	0 3 3 0	3·3	850	6,864	4,138	2,080	1,254	$\frac{1}{2}$ „ $\frac{1}{2}$
2 Holmes	9 10	4 4	5 2	5 2 2 14	6·5	400	2,811	2,811	432	432	$\frac{1}{2}$ „ $\frac{1}{2}$
2 Gramme ..	5 2	2 7	4 1	2 11 0 0	10·5	420	11,396	6,869	1,085	654	$\frac{11}{16}$ „ $\frac{11}{16}$
2 Siemens, medium	4 4	2 5	0 10	0 7 2 0	6·6	850	14,134	8,520	2,141	1,291	$\frac{11}{16}$ „ $\frac{11}{16}$

These last three measures were taken with the machines coupled in multiple arc, the effect being a considerable increase in light produced for power expended.

M. Tresca has made a series of experiments in the establishment of MM. Sautter and Lemonnier, to ascertain the amount of work performed by the Gramme machine for the production of light.

The high speed at which the Gramme machine is driven, rendered it difficult to employ a dynamometer which should not make more than 250 revolutions a minute. The diagrams obtained were, however, satisfactory after some preliminary trials. The work done has thus been accurately determined, but this was not the case with the luminous intensity. This latter was measured direct by a photometer with two discs, one illuminated by a Carcel lamp, and the other by the electric lamp. One of these discs appeared of a green hue in relation to the other, which was rose-tinted, and amongst the various methods tried, it was found decidedly the best to correct the difference of these tints by the interposition of two Carcel lamps, burning 1·48 oz. an hour, and at a suitable distance from the photometer, the electric light being placed at a distance of 131·23 ft. in the first, and 65·61 ft. in the second trial.

In spite of the uniformity of the electric current supplied to the regulator, the light, on account of the irregularity in the nature of the carbons, showed oscillations, which for the most part were perceptible only in the photometric determinations, but on that account a great difficulty arose in determining exactly the intensity and its definition in relation to the expenditure of power.

It was only possible to avoid these drawbacks by increasing the number of trials, and limiting their duration to very short periods. The standard lamp having been placed in such a position as to balance the average intensity of the electric light, the apparatus was kept at work during a certain time, and at the instant that an apparent equality was observed, a signal was given to the experimenter stationed at the dynamometer, and a diagram comprising a period of a few seconds was obtained. Another observer recorded the speed of the dynamometer each minute, and the dynamometer diagram was renewed only at a fresh signal from the operator at the photometer. Tables IX. and X. give all the data obtained from the successful experiments thus conducted.

TABLE IX.—EXPERIMENTS WITH LARGE GRAMME MACHINE.

Ratio of distances of electric light and Carcel lamp from photometer 40 : 93
Ratio of intensities .. .. 40 : 93 = 1850

Numbers of Diagram.	Revolutions of Dynamometer a Minute.	Mean Ordinates given by the Diagrams.	Foot-pounds of Work a Second.
		in.	
1	238	·885	4883
2	251	·744	4324
3	248	·854	4916
4	244	·653	3693
5	241	·614	3226
6	244	·654	3716
Mean	244	..	4127 = 7·5 { H.-P. a minute.

Work done for 100 burners .. .. 7·5 : 1850 = 405 horse-power.
Work each burner a second .. .. 2·23 foot-pounds.

TABLE X.—EXPERIMENTS WITH SMALL GRAMME MACHINE.

Ratio of distances of electric light and Carcel lamp from photometer 20 : 1·15
Ratio of intensities .. .. 20 : 1·15 = 302·4

Number of Diagram.	Revolutions of Dynamometer a Minute.	Mean Ordinates of Diagram.	Work done in Foot-pounds a Second.
		in.	
1	234	·279	1452
2	238	·262	1445
3	244	·292	1651
Mean	239	..	1516 = 2·75 { H.-P. a minute.

Work done for 100 burners .. .. 2·75 : 302·91 horse-power.
Work each burner a second .. .. 4 : 97 foot-pounds

In order to ascertain the number of revolutions of the main shaft of the magneto-electric machine, it was necessary to make certain that there was no slipping of the driving belt. By various experiments, the speed of the two shafts was tested by means of two counters, and it was thus found, in the first trial, that the actual ratio of the speed was 5·18, the ratio calculated from the diameters of the pulleys, and the thickness of belts being 5·26. The speed of the Gramme

machine shaft was thus found by multiplying the mean speed of the dynamometer shaft by 5·22, which gave for the first series of trials, 1264 turns a minute; in the second series, the ratio of speeds being only 3·65, and the mean speed of the dynamometer 239 turns a minute, the number of revolutions of the machine was $239 \times 3 \cdot 65 = 872$. The apparatus, which gave a light of 1850 Carcel lamps, is arranged as follows;—The horizontal shaft carries two series of conductors placed symmetrically, the one on the left receiving the current from 15 bobbins spaced around a soft-iron ring. In the intervals between these are 15 other bobbins in connection with the conductor placed on the other side of the shaft. The two currents combine when the bobbins turn around the shaft in front of the poles of the four electro-magnets, put in operation by a portion of the current, the balance being led off to the electric lamp. The following are the leading dimensions of the machine;—

Electro-magnets;—	
Diameter of the electro-magnet	2·75 in.
Length	15·90 „
Diameter of coil	5·19 „
„ wire	·125 „
Weight of copper rolled around each electro-magnet	52·8 lb.
Bobbins;—	
Outside diameter of soft-iron ring	7·67 in.
Inside „ „	6·18 „
Width of soft-iron ring	4·68 „
Outer diameter of bobbin	9·05 „
Inner „ „	4·72 „
Diameter of wire	·1 „
Total weight of wire	308 lb.
Diameter of conducting cylinders	3·54 in.
„ lamp wire	·3 „
Machine;—	
Total length, including pulley	31·5 „
„ height „ „	23·03 „
„ width „ „	21·65 „

The machine giving a light of 3000 Carcel lamps is more simple, as it has only a single series of conductors and small bobbins, and two electro-magnets only. The following are its leading dimensions —

Electro-magnets;—	
Diameter	2·75 in.
Length	13·97 „
Diameter of coil	4·72 „
„ wire	0·15 „
Weight of copper around electro-magnet	31·5 lb.
Bobbins;—	
Outside diameter of soft-iron ring	6·61 in.
Inside „ „	4·84 „
Width of soft-iron ring	3·97 „
Outside diameter of bobbin	4·68 „
Inside „ „	4·05 „
Diameter of wire	·07 „
„ conducting cylinder	3·5 „
„ wire to lamp	·34 „
Machine;—	
Total length, including pulley	25·6 „
„ height „ „	19·92 „
„ width „ „	16·14 „

The large machine supplies a lamp made at the works of M. Gramme, with carbons of ·123 sq. in. in section; the lamp for the smaller machine was made by M. Serrin, with carbons of similar dimensions.

The machines worked with regularity for a sufficient time to prove the absence of heating. Moreover, the work done was very uniform during the experiments, although one of them was considerably prolonged.

As regards the cost of different modes of lighting, the following data are of interest. The consumption of oil for 1850 Carcel burners an hour equals $1850 \times 1 \cdot 48$ oz. = 2738 oz., or about 6800 cub. ft. of gas. Under these conditions the cost of fuel would be only the hundredth part of cost in oil, and one-fiftieth part of the cost of gas-lighting in Paris. The comparison is less favourable for smaller machines, for from the data given it will be seen that for the large machine, each Carcel burner requires 2·23 foot-pounds, and for the small machine, 4·97 foot-pounds, or double the former. This expenditure of work would, according to M. Heilmann, be increased to 1·85 foot-pounds for each burner in a hundred-light machine.

A lamp of 100 burners, to light a workman as well as would an ordinary lamp placed 18 in. away from him, may be situated 16·5 feet away; a lamp of 300 burners may be 28·5 ft., and one of 1850 burners at 70 ft. 4 in.; these figures show that the largest sizes of lamps may be most usefully employed for lighting manufactories.

During the competitive trials at the Franklin Institute, as to the relative efficiency of the machines as noted in the preceding pages, Professors Houston and Thomson took the opportunity

thus afforded to make a careful study of many interesting circumstances which influence the efficiency of these machines.

A convenient arrangement of the particular circumstances to be discussed is, those affecting the internal work of the machines; those affecting the external work; and the relations between the internal and external work.

The mechanical energy employed to give motion to a dynamo-electric machine is expended in two ways; in overcoming the friction and the resistance of the air; and in moving the armature of the machine through the magnetic field, the latter, of course, constituting solely the energy available for producing electrical current.

The greatest amount of power expended in the first way was noticed to be about 17 per cent. of the total power employed. This expenditure was clearly traceable to the high speed required by the machine. The speed, therefore, required to properly operate a machine is an important factor in ascertaining its efficiency. The above percentage of loss may not appear great; but when it is compared with the total work done in the arc as heat, constituting, as it did in this particular instance, over 50 per cent. of the latter, and about 33 per cent. of the total work of the circuit, its influence is not to be disregarded. In another instance the work consumed as friction was equal to about 80 per cent. of that appearing in the arc as heat, while, in the Gramme machine experimented with, this percentage fell to 20 per cent. of that which appeared in the arc as heat, and was only about 7 per cent. of the total power consumed in driving the machine.

In regard to the second way in which mechanical energy is consumed, in overcoming the resistance necessary to move the armature through the magnetic field, or, in other words, to produce electrical current, it must not be supposed that all this electrical work appears in the circuit of the machine, since a considerable portion is expended in producing local circuits in the conducting masses of metal, other than the wire, composing the machine.

The following instances of the relation between the actual work of the circuit, and that expended in local action, will show that this latter is in no wise to be neglected. In one instance an amount of power somewhat more than double the total work of the circuit was thus expended. In this instance also it constituted more than five times the total amount of power utilized in the arc for the production of light. In another instance it constituted less than one-third the total work of the circuit, and somewhat more than one-half the work in the arc.

Of course, work expended in local action is simply thrown away, since it adds only to the heating of the machine. And, since the latter increases its electrical resistance, it is doubly injurious.

The local action of dynamo-electric machines is analogous to the local action of a battery, and is equally injurious in its effects upon the available current.

Again, in regard to the internal work of a machine, since all this is eventually reduced to heat in the machine, the temperature during running must continually rise until the loss by radiation and convection into the surrounding air equals the production, and thus the machine will acquire a constant temperature.

This temperature, however, will differ in different machines, according to their construction, and to the power expended in producing the internal work, being, of course, higher when the power expended in producing the internal work is proportionally high.

If, therefore, a machine during running acquires a high temperature when a proper external resistance is employed, its efficiency will be low. But it should not be supposed that because a machine, when run without external resistance, that is, on short circuit, heats rapidly, that inefficiency is shown thereby. On the contrary, should a machine remain comparatively cool when a proper external resistance is employed, and heat greatly when on short circuit, these conditions should be regarded as a proof of its efficiency.

In regard to the second division, the external work of the machine, this may be applied in the production of light, heat, electrolysis, magnetism, and the like.

Where it is desired to produce light, the external resistance is generally that of an arc formed between two carbon electrodes. The resistance of the arc is therefore an important factor in determining the efficiency. To realize the greatest economy, the resistance of the arc should be low, but nevertheless should constitute the greater part of the entire circuit resistance.

In some measurements the resistance of the arc was surprisingly low, being in one instance 0·54 ohm, and in another 0·79 ohm. It was, however, in some instances as high as 3·18 ohm. The amount of work appearing in the arc, as measured by the number of foot-pounds equivalent, is not necessarily an index of the lighting power.

Perhaps the highest estimate that can be given of the efficiency of dynamo-electric machines, as ordinarily used, is not over 50 per cent.; measurements have not given more than 38 per cent. Future improvements may increase this proportion. Since the efficiency of an ordinary steam-engine and boiler, in utilizing the heat of the fuel, is probably over-estimated at 20 per cent., the apparent maximum percentage of heat that could be recovered from the current developed in a dynamo-electric machine would be over-estimated at 10 per cent. The economical heating of buildings by means of electricity may therefore be regarded as totally impracticable.

In respect to the relations that should exist between the external and the internal work of dynamo-electric machines, it will be found that the greatest efficiency will, of course, exist where the external work is much greater than the internal work, and this will be proportionally greater as the external resistance is greater. Measurements gave, in one instance, the relation of ·82 ohm of the arc to ·49 ohm of the machine, a condition which indicates economy in working. The other extreme was found in an instance where the resistance of the arc was 1·93 ohm, while that of the machine was 4·60 ohms, a condition indicating wastefulness of power.

DYNAMOMETER.

A dynamometer is defined as an apparatus for the measurement of force expended or work done in various machines; its construction depends on the purpose of the machine to which it is applied, whether the machine is supplying or consuming power.

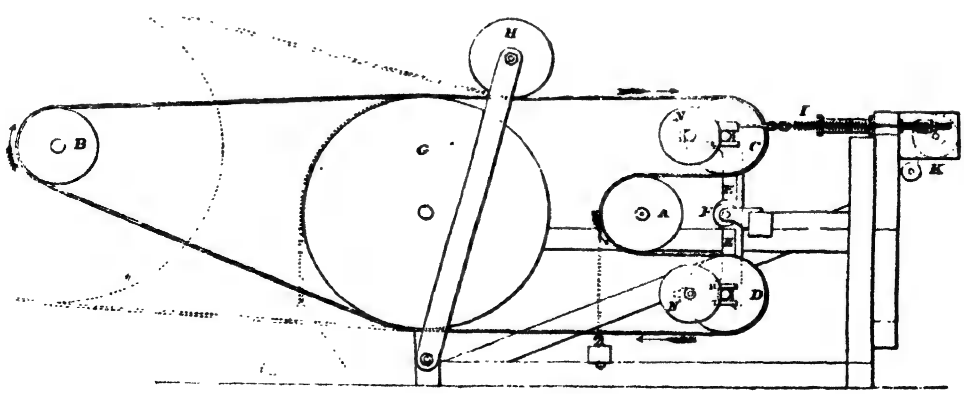
The steam-engine indicator is capable of being applied, with considerable accuracy, directly to power-supplying, and indirectly to power-consuming, machines; but in trials where it is desirable that the conditions under which each machine is tried, shall most nearly correspond with those under which it will have to perform its ordinary duty, it is preferable to substitute for the indicator two distinct forms of dynamometer, one to the power-consuming, the other to the power-supplying, machines. Both forms of dynamometer should be so constructed as to determine results in the gross, to record as a whole the performance of a given task, and the whole power developed by the combustion of a given supply of fuel.

W. Froude, in the 'Proceedings' of the Institution of Mechanical Engineers, 1858, describes a form of dynamometer adapted for machines consuming power. The description of this dynamometer and the accounted results obtained with it, should be read in connection with the article on Belts in this Supplement.

The belt dynamometer is designed to record by a diagram the performance of any power consuming machine which is usually driven by a belt, or can be so driven on the occasion of the trial.

The conditions of force under which a belt transmits power to the machine it drives are the following. The belt must possess a sufficient amount of tension to maintain the necessary adhesion upon the pulleys; and if the machine were entirely free from friction, and were once put in motion without any load or duty, this fundamental tension would continue equally great in both the leading and trailing sides of the belt. If the machine be loaded, and the friction of the working parts always forms a portion of the load, the driving belt must be tighter on the leading side than on the trailing, otherwise the motion will cease on the application of the load. The difference of tension between the two sides of the belt which must be thus brought into action, in order that motion may continue while the resistance of the load is in operation, is the exact measure of that load; and if this difference of tension is known, the power consumed can be calculated, in exactly the same way as if the pulley were driven simply by a force of the same amount acting at the circumference. The two elements of the power consumed will be the actual force at the circumference of the pulley, or the difference between the tensions of the leading and trailing sides of the belt, and the distance travelled by this force, which is identical with the travel of the circumference of the pulley, or of the belt itself. The power consumed, or the units of work expended during any instant, will be the product of the difference between the tensions of the leading and trailing sides of the belt at that instant, multiplied by the space in feet travelled by the belt during that instant. The object of the belt dynamometer is, to obtain by a direct process a continous record of the difference of tension between the leading and trailing sides of the belt, combined with the space travelled during each instant, throughout the period occupied in the completion of a given task; and if the total time occupied be noted, these recorded data can be at once converted into average horse-power consumed. The difference between the two tensions is ascertained by a direct process, analogous to that of weighing one against the other at the opposite ends of a scale beam; in such a manner as to maintain equilibrium, not by adding weights to the lighter end, but by supporting the heavier end by a spring balance, the extensions of the spring measuring the excess of weight at the heavier end.

Figs. 1065 to 1067 explain the construction. The power is applied by the pulley A, Fig. 1065, and is received and consumed by the pulley B of the machine under trial, the motion taking place in the direction of the arrows. The belt by which the power is conveyed from A

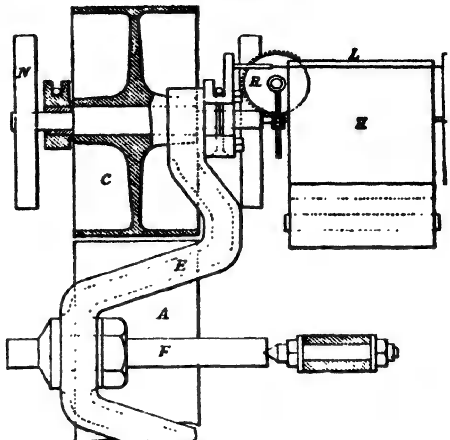


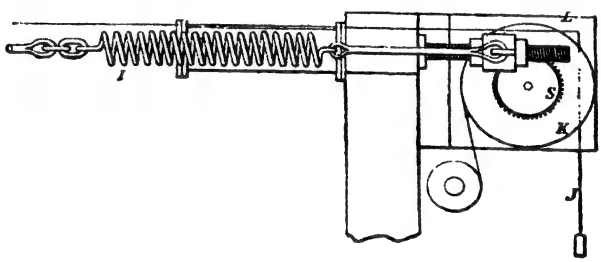
to B passes over the pulleys C and D, carried at opposite ends of the scale beam or swing beam E, and centred on it at equal distances from F. The upper and lower portions of the belt pass over the guide wheel G, and are retained parallel, though the swing beam E be made to move through an angle of many degrees. In case the pulley B of the machine be of larger diameter or at a higher level than the guide wheel G, a supplementary guide pulley H is employed to preserve the parallelism of the two portions of the belt.

In this arrangement the tight or leading side of the belt passes round the upper pulley C on

the swing beam, and the slack or trailing side round the lower pulley D; so that the pulley C is pressed horizontally by the tension of the tight side of the belt, and the pulley D by that of the slack side. These two tensions being equal, the swing beam E remains in equilibrium, and rests indifferently in any position within a moderate inclination to the vertical line. But when unequal, the spring balance I receives the pressure resulting from the inequality, and indicates the amount. The difference of tension varies with the varying duty performed by the machine under trial; the variations of the spring, being recorded continuously, together with the space travelled by the belt during the same instant, will furnish the measure of the power consumed. The total tension on each side of the swing beam pulleys is double that of the respective portions of the belt, because the tension of the belt acts on both sides of the pulley, so that the spring balance indicates double the difference between the tensions of the tight and slack sides of the belt, allowed for by the mode of constructing the scale of tension on the diagrams.

1066.





The apparatus by which the dynamometer is self-recording consists of a cylinder K, Figs. 1066, 1067, mounted in a frame attached to the end of the instrument, which is made to revolve by means of a screw and worm wheels connected with the upper pulley C; the screw is provided with telescope and universal joints, so as to allow of the vibration of the beam, one end of the screw resting on the movable arm of the swing beam, while the other is carried by the frame in which the cylinder is mounted. The revolutions of the recording cylinder represent on a reduced scale the revolutions of the pulley C. At the same time the pencil L receives a motion direct from the swing beam E, being connected with the upper end of the swing beam by the cord J; it is mounted in an arm which has a sliding motion parallel to the axis of the cylinder, and so placed that the pencil presses lightly on the surface of the cylinder. The tendency of the spring balance to oscillate above and below its proper position, is checked by means of an oil cylinder provided with a loosely fitting piston, which is attached to the spring balance. There is also a communication between the two ends of the cylinder by means of a passage fitted with a stop-cock. The recording cylinder K, is provided with a continuous sheet of paper, and as it revolves, the pencil traces on the paper a curvilinear area, in which each increment in length represents the corresponding space travelled by the belt; while the height at that point, measured from the datum line traced by the pencil when the spring balance is at zero, represents the stress upon the spring balance while the belt travelled through that space. The aggregate area included in any length of diagram represents the units of the work performed.

The swing beam E, Fig. 1066, is so constructed that the belt can be slipped on and off the pulleys when required, and the pulleys are overhung. The pulleys should be relieved as completely as possible from the friction produced by the tension of the belt, for this friction will be combined with the resistance experienced by the belt, and will thus form part of the force recorded in the diagram, and be improperly charged to the machine under trial. Both these requirements are met by carrying each pulley in a bent bracket fixed to the end of a swing beam, having a friction roller N on each side, against which the journals of the pulley bear. Such an arrangement would be somewhat one-sided in supporting the pulleys, and some oblique deflection would be produced by the stress of the belt, causing the pulleys to be deflected from their true working plane so that the belt would run unevenly; and this was obviated by cranking the arms of the swing beam in the plane of the axes of the pulleys, so as to introduce a duly compensating deflection in a direction opposite to that in which the axes of the pulleys are deflected. By this means the axes of the pulleys are preserved truly parallel to the axis on which the swing beam vibrates.

In reference to the amount of stress brought upon the swing beam, the working tension of the belt is composed of two distinct forces, the fundamental tension of the belt whereby the requisite adhesion is maintained, and the excess of tension constituting the driving force. The excess of tension or the driving force is wholly taken up by the springs of the indicating apparatus, and the fundamental tension of the belt alone constitutes the stress upon the beam, which must accordingly

be strong enough to give sufficient adhesion for the greatest driving force that the dynamometer will have to measure. It appears by experiment that when a belt is passed over a pulley with a weight suspended from each end, the arc of contact being a semicircle, the lighter weight must be at least one-third of the heavier in order that the belt may not slip; but practically it is better to reckon the lighter one-half of the heavier, in order to be secure against the loss of power that would result from the belt slipping. The lighter weight is thus equal to the difference between the two weights.

The dynamometer is so arranged that the tight side of the belt always runs upon the upper pulley C, and the indicating apparatus K is placed on a level with it; this arrangement accords with the direction of motion invariably adopted in the construction of thrashing machines.

The motion of the recording cylinder K, is transmitted from the upper pulley C on the swing beam, through the two successive worm wheels R S, and each of which reduces the speed to $\frac{1}{50}$th, so that the rate of rotation of the recording cylinder is $\frac{1}{2500}$th of that of the pulley. To avoid the errors which might creep into the analysis of the diagrams. by constructing the longitudinal scale from the compound ratio of speed and diameter alone, the first worm wheel R carries a cam, which at each revolution acts upon a subsidiary pencil placed alongside the indicating pencil; as long as the subsidiary pencil is unmoved it traces a straight base line lengthways of the paper, but each action of the cam produces a momentary deviation, which forms a narrow indent on the base line, each indent marking the completion of 50 revolutions of the pulley, or the travel of 157 ft. of belt, the pulley having a circumference of 3·14 ft.

As in the analysis of the diagram, each of these divisions marked by the cam stands for the unit of distance in calculating horse-power, the calculation is much simplified if the diameter of the pulley is made ⅝ in. larger than 1 foot, giving a circumference of 3·3 ft., so that 10,000 revolutions give 33,000 ft.

The scale of tension in the diagrams is determined as follows;—The working belt is removed, and replaced by a belt attached at one end to a fixed point in the foot of the frame, as shown dotted in Fig. 1065, passing over the power-supplying pulley A, which then serves merely as a guide pulley, then round the upper pulley C on the swing beam, and over the large guide pulley G. The loose end of the belt is provided with a dish to hold the weights used in determining the scale. Any weight suspended at the extremity of the belt will give exactly that stress on the indicating springs which would be produced by an effective driving force of the same amount. The dish with its appendages make up a weight of 50 lb., and bring the indicating pencil to the same position that it would have if a machine were under trial with an effective driving power of 50 lb.; a small motion given to the paper cylinder by hand, marks on the paper the position of the pencil. The same operation is repeated with such successive increments of weight as serve to make up a convenient fundamental scale, and whatever irregularity there may be in the springs themselves, or whatever want of equilibrium in the swing beam, the scale thus constructed is accurate, since it is made by the identical forces which it will have to record and measure. In order that this scale of tension may appear throughout the entire length of each diagram, eight adjustable pencils carried in a frame rest upon the paper, just clear of the path of the indicating pencil, each of which is adjusted accurately to one of the lines marked in the formation of the scale; as the diagram proceeds, each pencil rules a straight line on the paper, showing the position due to the force which it represents. This greatly facilitates the analysis of the diagram, and adds to the accuracy of the results; and a further facility is obtained by using pencils of distinctive colours; for example, each 100 lb. line red, and each 50 lb. line blue.

Friction brakes, or dynamometers, are adapted for measurements with power supplying machines; and act upon the principle of absorbing by a friction brake the power given out by an engine when working at regular speed and pressure, and measuring the weight required to give the necessary amount of friction to absorb the whole power. The simple form of brake first used for this purpose has undergone considerable modifications: for an instrument is required which can be maintained in continued action for a long period without any variation in the resistance which it offers to the motion of the engine; so that the total power developed in each case may be accurately ascertained, without any correction being required for variation in the resistance overcome during the period of trial.

In the brake dynamometer of J. Imray the friction or hold of a belt upon a drum is held to be independent of the diameter of the drum; for although it has been sometimes considered that a belt, of given width, drives a drum of large diameter, with less slip than one of small diameter, and this may be the case if the belt be rather rigid, and the comparison be made between a large drum round which the belt can easily bend, and one so small in diameter that the resistance of the belt to flexure prevents it from bearing fully on the surface of the drum, yet within fair limits, and with belts of sufficient flexibility, the diameter of the drum has no effect whatever on the friction of the belt upon its surface. This has been experimentally proved by J. Imray with drums of various sizes ranging from 5½ in. to 14 in. diameter, and from 15¾ in. up to 38¾ in. diameter, in the following manner. The drum was held fast in its bearings, and a belt passed over it so as to embrace half the circumference, with weights P and W hung from its extremities. The larger weight W was gradually increased until it just made the belt slip; and consequently the excess of W over P exactly measured the friction of the belt. The ratio of W to P was thus determined, and it is evident that if with a given arc of contact this ratio be found to remain invariable, whatever be the diameter of the drum, then the friction also is independent of the diameter. In this manner five drums were used of small diameter, ranging from 5½ in. to 14 in. The same belt was employed with each drum; it was very flexible, 1⅝ in. broad and ⅛ in. thick, weighing about 2 lb., and in reckoning the values of P and W, half the weight of the belt or 1 lb. was added to each of the actual weights suspended. The following results were obtained showing the values of the ratio of W to P with the different diameters of drums.

From these experiments it appears that the largest drum presented almost exactly the same

friction as the smallest; and the results of all these fifteen experiments agree so nearly that it may safely be inferred that the diameter does not affect the amount of friction.

Number of Experiment.	Diameter of Drum.	Weight of P.	Weight of W.	Value of Ratio $\frac{W}{P}$.	Mean Value of Ratio $\frac{W}{P}$.
	inches	lb.	lb.		
1		18	29	1·611	
2	5·5	34	57	1·676	1·675
3		65	113	1·738	
4		17	29	1·706	
5	7·6	32	57	1 781	1·733
6		66	113	1·712	
7		17	29	1·706	
8	9·8	32	57	1.781	1·733
9		66	113	1·712	
10		18	29	1·611	
11	11·8	34	57	1·676	1·642
12		69	113	1·638	
13		17	29	1·706	
14	14·0	34	57	1·676	1·673
15		60	113	1·638	

Average Value of Ratio $\frac{W}{P} = 1{\cdot}691$.

Three drums were tried of the diameters 15·8 in., 24·0 in., and 35·8 in. respectively. The largest drum was well polished and greasy, the smallest was turned but not polished, showing the tool marks; and the intermediate size was also turned, but not quite so smooth as the smallest. In these experiments also the belt was tolerably flexible, about 3 in. broad and $\frac{3}{16}$ in. thick; and the weight of the belt and scales for receiving the weights being 28 lb., half that amount, or 14 lb., was added to each value of P and W. The following were the values of the ratio of W to P with the different diameters of drum.

Number of Experiment.	Diameter of Drum.	Weight of P.	Weight of W.	Value of Ratio $\frac{W}{P}$.	Mean Value of Ratio $\frac{W}{P}$.
	inches	lb.	lb.		
16		14	37	2·643	
17	15·8	42	107	2·548	2·697
18		70	203	2·900	
19		14	35	2·500	
20	24·0	21	49	2·333	2·322
21		42	91	2·167	
22		70	160	2·286	
23		14	42	3·000	
24		16	49	3 063	
25	38·8	20·5	60	2·927	3·129
26		28	94	3·357	
27		41	126	3·073	
28		70	235	3·357	

Average Value of Ratio $\frac{W}{P} = 2{\cdot}716$.

From these experiments it appears that while the largest of the drums presented the greatest friction, yet the smallest presented more than the intermediate size, and the discrepancy is readily accounted for by the difference in the smoothness or polish of the surfaces. In neither set of experiments does the result with any of the drums differ from the average more than may fairly be accounted for by variations in the polish of the surface.

That the friction of a belt is thus independent of the diameter of the drum which it embraces, is the result arrived at also by theory. The formula obtained by theory for the ratio of W to P is—

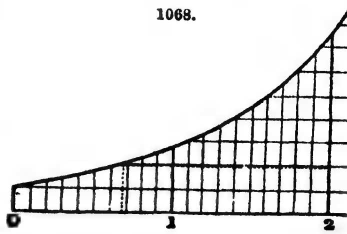
$$\log._\epsilon \frac{W}{P} = f \times a, \quad \text{or} \quad \frac{W}{P} = 2{\cdot}72 f \times a;$$

2·72 being the base of the hyperbolic logarithms, f the coefficient of friction or the ratio of the friction to the pressure, and a the angle of the arc of contact of the belt with the drum. This formula does not involve the diameter of the drum, and accordingly shows that the friction is independent of the diameter. It is matter of common observation that, when a belt is overloaded with work and slips on the drum, the slip is prevented by substituting a drum of larger diameter; still this effect does not result from an increase of friction being obtained with the larger drum, but

simply from the circumstance that the velocity of the circumference of the larger drum being greater, at the same number of revolutions a minute, the friction required to transmit the same amount of horse-power is proportionately less, and accordingly falls below the limit at which the belt begins to slip.

This formula is represented as a curve in Fig. 1068 by means of which the value of the ratio of W to P may be readily found, for any values of the coefficient of friction and arc of contact. Thus if the coefficient of friction f be ⅓ or 0·33, and the arc of contact a be 2, that is twice the radius, then the product $f \times a$ is 0·67; and finding this point on the base line, the corresponding height is 1·95, which is therefore the value of the ratio of $\frac{W}{P}$.

1068.

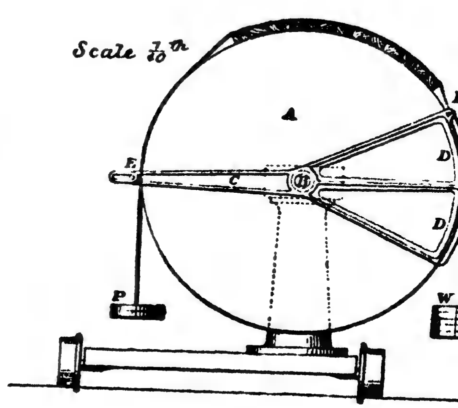


In order to check the formula, the drums were held fast in their bearings as before, and an adjustable roller was introduced between the belt and the circumference of the drum, so as to vary the extent of circumference embraced by the belt. The number of degrees in the arc of contact was approximately estimated. The following values of the ratio of W to P were obtained;—

Number of Experiment.	Diameter of Drum.	Arc of Contact.	Weight of P.	Weight of W.	Value of Ratio $\frac{W}{P}$.	Mean Value of Ratio $\frac{W}{P}$.	Theoretical Value of Ratio $\frac{W}{P}$.	Error per cent.
	inches	degrees	lb.	lb.				
29			14	25	1·786			
30	15·8	120	42	84	2·000	1·962	1·938	1¼
31			70	147	2·100			
32			14	24	1·714			
33	24·0	123	42	78	1·857	1·809	1·778	1¾
34			70	130	1·857			
35			14	34	2·429			
36			16	39	2·437			
37	38·8	144	21	52	2·476	2·506	2·491	½
38			28	70	2·500			
39			42	109	2·595			
40			70	182	2·600			

These experiments fully confirm the results arrived at by theory, in reference to the relation of the friction to the arc of contact; and this relation may be illustrated by the fact that the friction obtained by two turns of rope round a post, whatever be its diameter, is the square of that obtained by a single turn, while three turns raise it to the cube, and so on. Thus a single turn of a hemp rope round an oak post gives a value of say 9 very nearly for the friction; or in other words a tension of 1 lb. applied at one end of the rope will resist a tension of 9 lb. at the other: two turns then give a friction of 9 × 9 or 81; three turns a friction of 9 × 9 × 9 or 729; and so on, every additional coil thus giving an enormous increase of friction.

1069.



The results of the above experiments were applied to the construction of an accurate instrument for the measurement of power by means of a friction brake or dynamometer. In the previous instruments of this kind, the total friction of the belt on the drum, after having been originally adjusted in amount by the weights suspended from the belt, is then regulated to maintain the instrument in its correct adjustment: this is accomplished either by means of a tightening screw in the belt adjusted continuously by hand, as in the earlier dynamometer; or by means of a lever with unequal arms, as in Appold's friction brake.

By taking advantage of the principle that the friction varies with the extent of the arc of contact, the brake dynamometer is applied, Fig. 1069. The friction drum A is fixed on the shaft B driven by the engine or other power to be measured. Two radial arms C C are fitted one on each side of the drum A, having their extremities D D formed to coincide accurately with an arc of the circumference of the drum; the arms are capable of revolving freely on the shaft B, and their other extremities are connected together by a weighted bolt E, by means of which they are balanced upon the shaft. The friction belt is attached by a pin at one end F to the radial arms C, and at the other end is

suspended the counterbalance weight P, keeping the belt in close contact with the drum over the arc E F. The load W is suspended from the extremities D of the radial arms, by means of two thin brass straps or chains passing over the arcs D, on each side of the drum, and not in contact with its circumference.

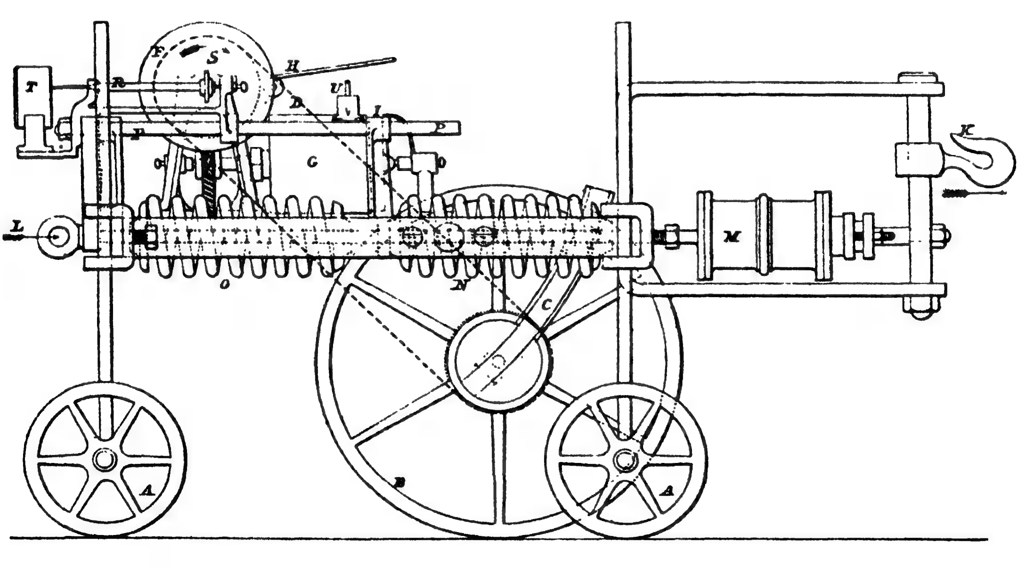
The action of the dynamometer is as follows: While at rest, the load W remains on the ground, but by putting the drum in rotation, the friction belt being strained tight by the counterbalance P, and being in contact with the drum over the arc E F, presents sufficient friction to raise the load W, and with it the radial arms C, which continue to rise, and by their rise to diminish the arc of contact of the friction belt, and reduce the amount of friction, until they assume such a position, that the counterbalance P and the friction of the portion of the belt in contact with the drum just balance the load W. Whenever the intensity of the friction is increased during the trial beyond the average, from heating or imperfect lubrication, the arms C will rise still further towards the extreme position, and further diminish the arc of contact E F; and whenever the intensity of the friction is diminished, as by the use of oil, the arms will fall back and increase the arc of contact E F until the friction will sustain the load; the total friction being thus preserved constant. The load W and counterbalance weight P are adjusted beforehand within proper limits, so that the vibrations of the arms C may be confined within the extreme positions.

In this brake dynamometer the load remains constant during the whole trial, and acts at a constant leverage by means of the arc D at the end of the arms C; while at the same time the total friction of the belt on the drum also remains invariable, being entirely unaffected by changes in the coefficient of friction, since a corresponding correction instantly takes place in the length of the arc of contact of the belt. In applying this dynamometer to measure the power of an engine, it is only necessary to take the difference in pounds between the load W and counterbalance weight P, and multiply it by the velocity of the circumference of the friction drum in feet a minute; the product of these divided by 33,000, gives the horse-power developed by the engine. In order to avoid any objection as to oscillation of the arms, which, though it would not affect the accuracy of the test, might seem objectionable to those whose engines were subjected to it, the counterbalance weight P is arranged in the form of a piston and rod immersed in a cylinder containing water; the piston fitting the cylinder so loosely that it could gradually assume the true position of equilibrium, while at the same time its movement is so much resisted by the water, that it could not undergo sudden changes of position. This arrangement renders the dynamometer as steady in its action as could be desired.

The oldest draught-testing instruments are spring links on dial balances, analogous to the Salter balance. One of these instruments is illustrated, p. 1302 of this Dictionary.

The divisions on the dial do not obey Hook's law of the distances travelled varying as the pulls, and it is necessary to determine all the divisions by actual experiment. Also the springs seem liable to twist, probably dependent upon the exact points at the ends at which the pulls are

1070.



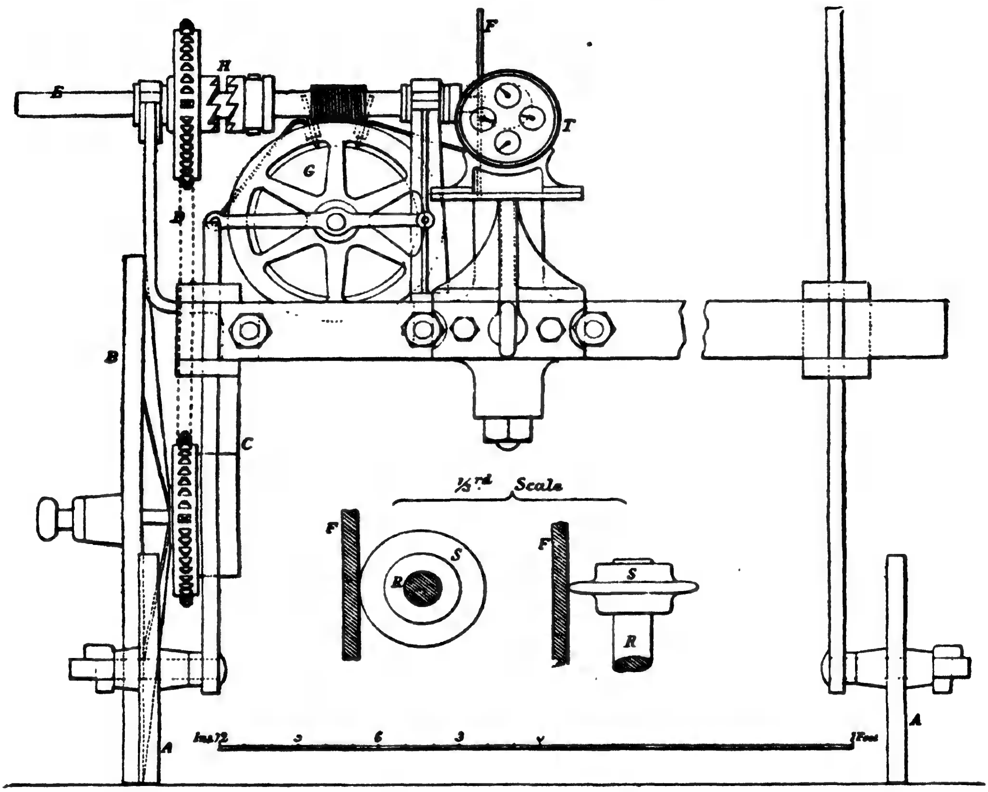
applied; and this, combined with a little wear of the pins in the lever, seriously affects the uniformity of action of the index hand.

The resistances of implements drawn by horses are very irregular and jerky, so that it is extremely difficult to read the mean draught on such an instrument with any degree of accuracy. These spring links have generally been superseded by integrating traction dynamometers.

The plough dynamometer, the first of these instruments, illustrated in Figs. 1070 and 1071, consists of a light wrought-iron frame, mounted on four wheels, three of these A A A being supported

on axles adjustable vertically and horizontally with clamps on the frame, exactly as in wheel ploughs; while the fourth wheel B, which is larger, is adjustable on the arc of a circle C, and drives the speed mechanism by a pitch chain and wheels D. The object of the vertical adjustments of the wheels is to permit one or two wheels to run in a furrow of any depth, while the others run on the unploughed surface. Generally, when in action, the small wheel on the driving side is lifted up altogether, to ensure that the traversing wheel shall always preserve its contact and driving power. By means of the pitch chain, the shaft E with the large gun-metal disc F at one end of

1071.



it, and the paper drum G, worked by a worm and wheel from the shaft, are driven at speeds proportional to the actual speed of the implement, as measured on the traversing wheel. They can, however, be disconnected at will by means of the clutch and handle H.

The paper drum is arranged to receive one sheet of paper, wound round it as in a steam-engine indicator, and a pencil attached to the frame is pressed against the paper by a spring, to draw a straight zero line on the paper as the drum revolves. On the end of the drum a distance index I is engaged, one revolution giving about 200 yards travel in the instruments for English use. The drum and this index can be disconnected, without stopping the rest of the working parts, by the screw at the end of the drum.

The horses are attached to the main frame and carriage at its front end K, and the implement to be tested is attached to the eye L at the back end of the draw-bar. This draw-bar is attached to the back end of the oil cylinder M, and a piston rod in this cylinder, attached to the extreme front of the carriage, assists in supporting it. The draw-bar is further supported by the three cross frames of the carriage, through which it passes; and two spiral springs N O embrace it. From the draw-bar rises a vertical cross-head, to which a horizontal guide bar P P is bolted. This bar slides through two of the cross frames, and across the frame of the large disc F, and it is mounted with head-stocks which support the ends of a delicately fitted shaft R, on which a small brass disc S is keyed or soldered, in such a position that when the instrument is unloaded it touches the large disc exactly at its centre. The small disc, generally about 1⅝ in. in diameter, is termed the integrating disc, and by means of its shaft, and a short piece of india-rubber tube forming a universal coupling, it works the small counter T at the back end of the bar; this counter is the integrating counter. The bar P near its front end carries a pencil U in a light spring, which presses it against the surface of the paper drum. The large disc is pressed against the edge of the small one by means of a spring contained in the hollow shaft which carries it. The revolutions made by the large disc in any time must be proportional to the distance traversed in that time, as measured by the traverse wheel which drives the disc. The pull of any implement applied to the draw-bar will compress the springs to an extent proportioned to the pull applied, and will move the small

disc across the face of the large disc to the same extent. If the edge of the small disc is exactly touching the centre of the large disc, when the springs are unloaded but not slack, the distance of the small disc from the centre of the large will also vary directly as the strain, and the velocity ratio of the discs will vary in the same proportion. The number of revolutions of the small disc in any experiment will depend partly upon the distance travelled, as measured by the revolutions of the large disc, and partly upon the pull of the implement. The number of revolutions of the small disc, multiplied by a constant coefficient, is equal to the distance run multiplied by the pull, or to the foot-pounds of work done. Each set of springs has its own constant, determined experimentally.

In a perfectly adjusted instrument, with perfect springs, the constant could readily be determined from one set of such experiments; but in practice the constant thus determined is never exactly the same for the different loads.

It is desirable with this and other dynamometers, in testing each implement, to take two runs of about equal length in opposite directions, adjusting both counters to zero before the first run, and noting their registers after each run. The results are determined from the means of both runs. This precaution avoids risks of error from slight inclinations of ground, and gives immediately a ready check on clerical and instrumental errors. All distances recorded should be taken from the distance scale or counter, and not from measurements in the field, as the traversing wheel may alter its effective diameter by clogging, or might stop temporarily. The following is a simple and systematic sequence for tabulating results;—

Distance registered in ft.	d
Index registered	n
Index a ft. run	$\frac{n}{d}$
„ corrected	$\frac{n}{d} \pm \mathrm{R}$
Ft.-lb. a foot run, that is also mean draught in lb.	$\mathrm{C}\,(\frac{n}{d} \pm \mathrm{R})$

Where C is the constant of the machines.

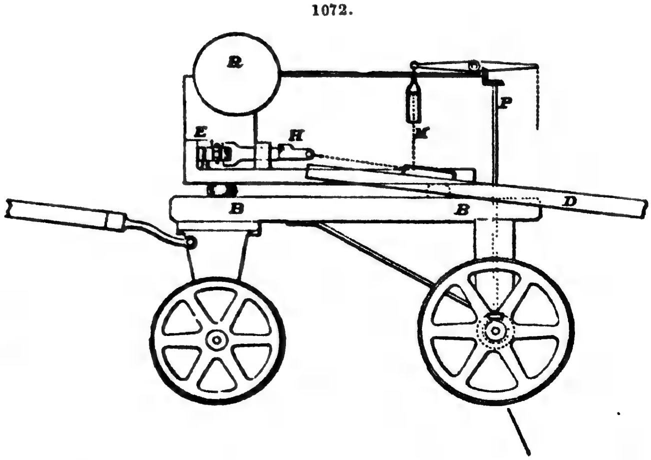
The paper cylinder referred to in the description of this instrument, enables diagrams of the strains and variations of strain to be taken during trials of implements. The paper being wound tight on the drum and secured, the zero pencil must be adjusted to mark clearly and steadily; then, the springs being unloaded, and the integrating disc at zero, the strain pencil must be adjusted to mark the cylinder on exactly the same line as the zero pencil. When the instrument is started, a diagram is produced of which the zero line forms the base; the abscissæ denote distances on the same scale as the distance index, and the ordinates show the strains on a scale of loads determined from the springs.

The horse dynamometer was designed primarily for testing carts, waggons, and other wheeled vehicles having shafts.

The general principle of this dynamometer is, that it shall occupy the same position as a powerful cart-horse in any wheeled vehicle to be tested; that it shall draw the vehicle on any sinuous course by means of harness attached to the shafts in the usual way; and that in doing this it shall register the most important strains which a horse would have to exert in drawing it.

All the instrumental parts are self-contained on a small bed-plate A A, Figs. 1072, 1073, mounted upon a carriage frame B B of wood and iron, resting upon four cast-iron wheels, which add to its stability by lowering the centre of gravity. E is a pair of untempered steel draught springs, which are of uniform width, with planed edges, and are jointed with an accurately fitted pin at one end, and two such pins with a short link at the other end. This arrangement prevents any tendency to parallel motion, as would be the case if there were links at both ends; and at the same time permits each bar freely to assume its own shape and length, when under strain, which could not be the case if the springs were attached immediately to one another at both ends. The longitudinal section of the springs is approximately parabolic, the bases being at the centre eye in each case. There are three pairs of these springs readily interchangeable, two pairs being 4 ft. long between end centres, and suited for maximum pulls of 600 and 1000 lb., and the third pair 5 ft. long, working up to 1600 lb. pull. The centre eye of the front spring is held by an accurately turned pin C, carried in a fork cast on the front end of the bed-plate; the eye of

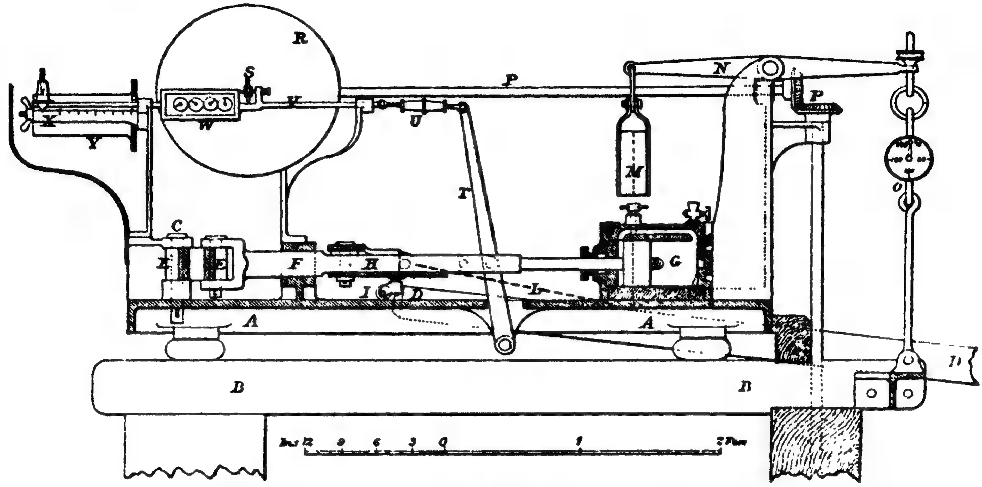
1072.



the other spring is similarly carried in a fork on the end of the turned draught bar, and is carried only in two bearings F behind the fork end, and the oil cylinder G at the back of the bed-plate.

Behind the bearing F the draught bar is flattened, and the draught plate H H is jointed to it with washers above and below, to ensure great freedom of motion horizontally. This draught plate is a very important detail, and represents a horse's shoulders and collar; it is attached to the

1073.



draught bar at its front end by the centre pin K, and the corners are supported on easy running castors I I, which move freely in any direction on the top surface of the bed-plate. To these corners, beyond the castors, and considerably behind the centre pin, are attached the draught chains L L, which are hooked to the shafts D D of the vehicle that is to be tested. The height of these chain attachments, and their width apart on the draught plate, are very nearly identical with the height and width of the similar attachments on the collar hames of a 16-hand horse; and the dynamometer therefore will draw a vehicle behind it round a considerable bend, always keeping both draught chains strained, and inclining the vehicle to follow in its track, without bearing materially against the inside of either of its shafts. The castors eliminate all vertical components of pull, so that only the direct horizontal components which are effective for doing work are communicated to the springs.

Above the oil cylinder G a wrought-iron chain saddle M, representing that carried by a horse in cart harness, is suspended from one end of the lever N, the other end of which is held by a Salter's balance O at the rear of the carriage. Over the saddle the ordinary shaft chains are passed, and the shafts being adjusted to their proper height by means of it, the weight carried on the saddle, in any experiment, can be read off readily on the dial referred to. Breeching chains are attached to the side frames, for restraining implements behind the instrument when going down hill. At the rear of the carriage, arrangements are made for testing any pair of springs readily in the field by means of a long ended bell-crank lever, the short arm of which can be linked when necessary to the back end of the draught bar, while to the long horizontal arm known weights are suspended at its outer end. The integrating and registering apparatus are similar in principle to those in the plough dynamometer previously described. The distance counter and large disc R are worked by means of bevel gear and shafts P P from the hind shaft of the carriage, which is keyed into one travelling wheel, while the other runs loosely upon it; a clutch and handle serve to disconnect or connect the gear readily. The motion of the draught bar is trebled on to the integrating disc S by means of the lever T, which has its fulcrum self-contained on the bed-plate, and at its upper end is connected by the link U to a small gun-metal sliding frame V, which rests in two easy fitting bearings, and contains in itself the integrating disc S, with its shaft and a simple and easily read counter W worked by it, for recording the number of revolutions of the disc. The front end of the slide also, beyond its bearing, carries a pointer X, for indicating to an observer the variations of draught and the maximum draught, on a clearly figured scale of loads. The distance register is kept on an equally clear counter behind the large disc, and worked by toothed wheels off the driving shaft.

The friction brake dynamometer, which absorbs the available energy of any prime mover by the friction of a strap on a pulley, and measures its amount at the same time, was invented by Prony, but improvements were introduced by Appold. Both forms of instruments have been described in this Dictionary, pp. 616 and 627.

The 100 horse-power friction brake is on the same principle, but has three brake pulleys on the same shaft. It consists of a cast-iron carriage and frames, supported on wheels and axles, for running on rails in a long trial shed, opposite to which the several engines to be tested should be parked. Two 5-in. bearings on the frames carry the main shaft, on which three brake pulleys, each 5 ft. diameter and 7 in. wide, are keyed, two of these being situated between the bearings, and the third on an extension of the shaft beyond them. To the end of the shaft a universal coupling shaft is keyed. Any engine to be tested adjusts its crank shaft as nearly as possible to the same

height and direction as the brake shaft, and then couples on to the universal coupling shaft with similar fork couplings, one of which is arranged to slide on the shaft so as to adjust the length exactly, and avoid risks of end friction on any of the journal collars of either engine or brake. Each of the three brake pulleys constitutes a complete brake in itself, and for moderate powers it is sometimes desirable to run with only one or two of them at work, the straps in that case being removed from the others. The brake also can be driven by a belt over one of these pulleys, if it is inconvenient to use the universal coupling shaft. Gun-metal side guides are screwed to the sides of the blocks to keep them in position laterally. On one side an eye is formed in the straps, and to this joint the testing weights are suspended by means of a rod. On the opposite side of the pulley the straps are cut, and connected again by means of the right and left-hand screw, for adjusting the degree of tightness by hand.

At its lowest point the strap is severed again, and the ends are connected by pins to a pendulum, sometimes called the differential lever. Its object is to maintain a uniform frictional resistance on the brake by keeping the joint of attachment of the weight at a constant level, and this it does with extreme delicacy in the following manner. The pendulum consists of two links suspended from joints on standards at each side of the pulley. Their length may be adjusted by nuts at their top ends, and by means of the joints in the standards they are free to move through angles of moderate extent on each side of their vertical position.

The first essential with this pendulum is that its length shall be less than the radius of the brake pulley, and the second is that the ends of the strap on the weight side of the brake shall be jointed to it, at a greater radius from its centre of suspension than the strap ends on the opposite side. A pointer on a standard marks the proper position for the joint, and the effect of the pendulum regulating apparatus is that, if, from any cause, the friction of the brake blocks increases, and lifts the joint above the pointer, thus circling the whole strap slightly round the pulley, the pendulum will incline towards the weight and slacken the strap in that direction to a greater extent than it tightens it in the opposite direction, in proportion as the radius of the one joint is greater than that of the other. The result is that the joint will return nearly to the pointer, and if from continued actions of this kind it should move materially from this its normal position, the strap must be slackened till the joint returns. A similar but directly opposite action takes place if the joint falls below the pointer, from the strap being too slack. The weight-rod carries at its bottom end a disc, which is a very easy fit in an open-topped cylinder or dash-pot, filled with water when the brake is in use. The weights are of different sizes, and are slipped on to the rod above a disc, which is screwed to it for supporting them at such a level as to be well above the top of the dash-pot, when the instrument is in use; but so that they can rest on the top flange of the dash-pot, when the brake is at rest, without pushing the pendulum very far over in the opposite direction.

The revolutions of the brake are registered on a counter, placed on a standard opposite the end of the shaft, and connected or disconnected at will by means of a handle and driving pins on the shaft and counter. Platforms are laid round the carriage for the convenience of the attendants, one of whom must always stand by the adjusting screws, and alter them when necessary to keep the joints opposite the pointers, while another looks after the lubrication and cooling of the straps and pulleys with water services. The usual lubricants used are tallow and blacklead, introduced in lumps between the wood blocks, with a little oil occasionally from lubricators suspended above the pulleys. Water cans with cocks are also placed above the pulleys for the water-cooling services, the supply to the cans being usually kept up by a small hose.

A forked steel gauge is provided for measuring the exact radius of the joint, at which the weights are suspended. To facilitate this measurement, the joint pin is turned down to sharp points at its ends, and the mean distance of these points on either side of the pulley from the shaft centre are taken by pressing the fork of the gauge against the shaft and reading off the figures on a scale at the other end of it. The gauge has also engraved upon it a scale of the circumference of the circles corresponding to the radii of the joint, and it is usually more convenient to read off this scale. The wood block beneath the joint is increased in length beyond the other blocks, partly to increase the bearing surface on the pulley there, and also to make the halves of the strap with its blocks, as divided by a vertical centre line, equal in weight. Then the effective load upon the brake is the load suspended by the rod including the weight of rod and washer-plates as measured with the bottom disc in water, together with the weights carried by the rod.

The foot-pounds of work a revolution then equals the effective weight W, multiplied by the circumference of the circle.

Putting W = total effective weight in lb., c = circumference in ft. of circle of radius of pulley n = number of revolutions in any time, t = time in minutes, then total foot-pounds of work done = $W \times c \times n$, and the mean actual brake horse-power $= \dfrac{W \times c \times n}{33{,}000 \times t}$.

In England it is usual in trials of portable and other engines to let each exhibitor determine the mean speed in revolutions a minute, and the horse-power at which he wishes his engine to be tried. Let r be the revolutions a minute, and P be the power which he elects for, then the gross weight on the brake must be

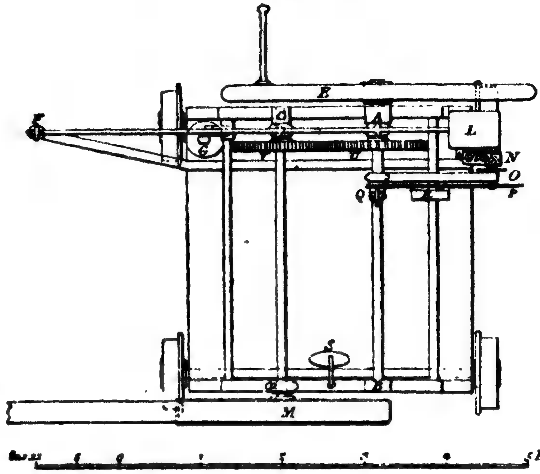
$$W = \frac{33{,}000 \times P}{c \times r},$$

and from this must be subtracted the weight of the rod, to determine the apparent weights which must be applied.

The rotary hand dynamometer, Fig. 1074, for testing small hand-worked machines, consists of a bed-plate and two frames, carrying two parallel shafts A B and C D, connected by a pair of toothed wheels U and V, each 14 in. diameter and 1¾ in. wide. The first of these shafts is supported in parallel bearings in the usual way, and carries at one end a fly-wheel E, 3 ft. 10 in. in diameter, with a handle at 16 in. radius, for working it by manual power. The second shaft has a bearing of

rounded internal section D at one end, to permit the shaft to incline slightly upwards at the other end. When the instrument is not in use, this shaft rests in the bottom of a slot C in the A frame, arranged to permit it to rise and circle round the centre of the shaft A B. At its end D, this shaft carries a belt pulley M, 2 ft. 7 in. diameter, and 4 in. wide, from which any machine to be tested is driven. A long lever F L encircles the two main shafts at C and A, and is prolonged to a heavy counterweight L at one end, and at the other suspends a Salter's spring balance F, attached to a cantilever projecting from the bed-plate. An oil cylinder G, below the lever, reduces any vibration which may arise in the apparatus. The lever is accurately bushed at A, so that the shaft A B can revolve within it, without allowing any transverse unsteadiness of the lever. The bush at C encircling the other shaft is rounded or knife-edged in the middle, to permit the shaft to rise in the slot as above described.

1074.

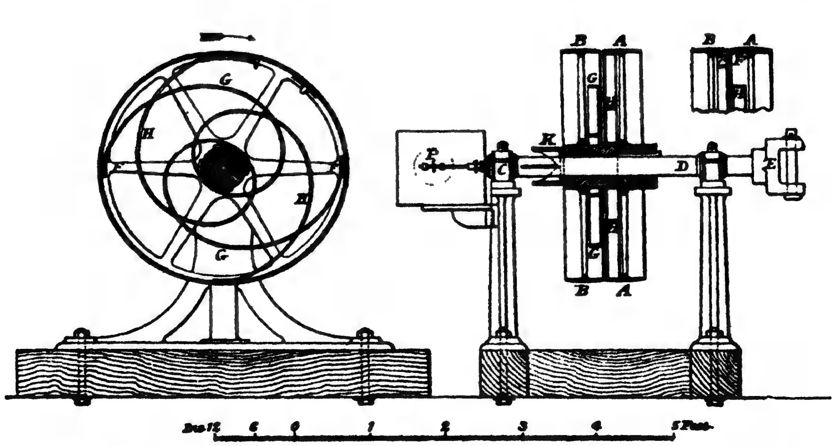


To the face of the weight L a counter N is attached. This is hinged at one end, with a spring behind it at the other, so as to press a small integrating disc contained in it against the face of a driving disc O, which is driven by a train of wheelwork P from the shaft A B. This wheelwork can be disconnected at pleasure by the clutch and handle Q; and it also drives a counter R, for registering the number of revolutions in a given time. The counterweight L, on the lever F L, must be adjusted lengthways, so as to balance the lever. To be accurate, half of the weight of the driving belt should at the same time be suspended from the driving pulley M, as that also must be balanced.

The counter N is shifted longitudinally on the face of the weight, till the integrating disc N is exactly opposite the centre of the disc O, when the lever is at the right height. The screw above the spring balance F must then be adjusted till the integrating disc N is exactly at the right height. The spring balance should now stand at zero on its scale, otherwise the balance of the lever must be further corrected with small weights.

The instrument is usually worked by two men, at nearly uniform speeds, regulated by the vibration of an adjustable pendulum suspended to the frame. The instrument being in true adjustment, the foot-pounds of work done in any revolution is equal to the pull in pounds upon the spring balance F, multiplied by the circumference in ft. of the circle whose radius is A F. This can be equated to the index recorded by the integrating counter N, multiplied by a constant C, which can be determined inversely by pressing the lever upwards till the spring balance records a certain strain, and then noting the integration recorded by the counter N in a given number of revolutions, by the revolution counter R.

1075. 1076. 1077.



Then if W = strain on spring balance in pounds, c = circumference in ft. of circle of radius A F, n = revolutions of integrating counter, N = revolutions of hand-wheel, the foot-pounds of work done, $N \times c \times W = C \times n$. Therefore $C = \dfrac{N \times c \times W}{n}$.

If the instrument is not in perfect adjustment when tested, and successive readings with

different loads on the spring are not exactly proportional to those loads, it will generally be found that the readings can be made proportional to one another, by adding to or subtracting from each reading the product of a constant K into the revolutions N. The result is that in all subsequent calculations $(n \pm K\,N)$ must be substituted for n.

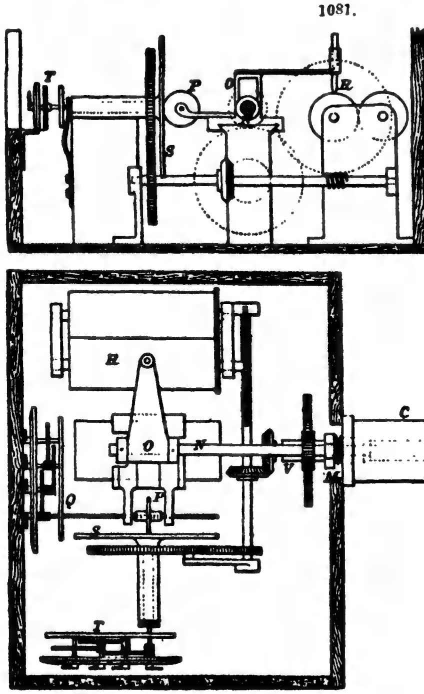
Then the foot-pounds of work done $= C\,(n \pm K\,N)$, and $C = \dfrac{N \times c \times W}{n}$.

The 20 horse-power rotary dynamometer, Figs. 1075 to 1077, consists of a pair of well-balanced fast and loose pulleys A and B, on a shaft C D, which is carried in bearings on two frames, supported on a timber carriage. The power of the engine or other prime mover is conveyed to the dynamometer, either by a belt on the pulley A, or by a universal coupling shaft. The machine under trial is driven by a belt from the pulley B, which, though loose upon the shaft, is connected with the pulley A by a series of springs, which permit it to lag behind the pulley A, the angles of twist being proportional to the effective strain transmitted by B.

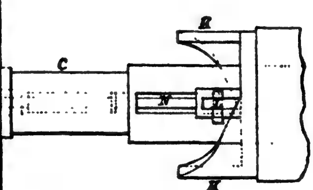
The springs are arranged in the following manner. The boss of the pulley B projects 2 in. beyond the edge of its rim; and from the inside of the rim of A two flat plates F F, at opposite sides project into the pulley B, Figs. 1076, 1077. To the boss of B and its elongation, four curved springs, shaped like short watch-springs, and each 2 in. wide by $\frac{5}{16}$ in. thick, are attached. Two of these G G, near the centre arms of B, wind outwards in one direction, and are attached to the pulley A, at its rim by means of the arms F F. The other two springs H H, on the prolongation of the boss of B, wind outwards in the opposite direction, and are attached direct to the rim of A. The object of arranging the springs in opposite directions is to neutralize the effects of centrifugal force upon them.

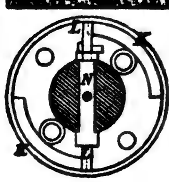
The pulley B is retained accurately in one position endways on the shaft by a collar on one side, and the boss of A on the other. On the boss of B, facing the bearing C, a very short piece of a

1081.



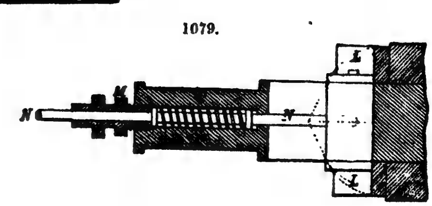
1078.





1080.

1079.



coarse-pitched double-threaded brass screw K is pinned, and these threads bear against a small cross-head L, which is passed through a slot in the shaft, and has its ends bevelled off to partial screw-threads so as to fit on the screw K, Figs. 1078 to 1080. The slot through the shaft extends nearly to the bearing C, giving the cross-head L freedom to slide along it in the direction of the bearing. From its extremity at M to the slot the shaft is bored out, and a small rod N passes up this bore and is screwed to the cross-head L. A light spiral spring encircles this rod in the bore, and

presses the cross-head L lightly against the screw K, the resistance at its other end being produced by the screwed bush at M.

The rod N is prolonged beyond the end of the main shaft, to work the slide O of a counter and disc integrating apparatus, Figs. 1078 and 1081. The slide works in V grooves and contains in itself an integrating disc P, supported on brackets projecting from the side, with its integrating counter Q, and a pencil for recording diagrams on a paper cylinder R. The driving disc S, the revolution counter T, and the paper cylinder turning gear are driven by means of a small spur pinion contained on the nut which is screwed into the main shaft at M. This pinion gears into a wheel on the counter apparatus, and thence the various motions are conveyed by bevel and other wheels, with a disconnecting clutch at V for stopping and starting the recording apparatus at pleasure.

As the angle moved through by the loose pulley B, relatively to the fast one A, varies nearly as the load on the springs, the travel of the cross-head L and slide O, worked longitudinally by uniform screw-threads, must vary in the same ratio. It follows from this that the motion of the pencil on the paper cylinder and the radius of contact of the integrating disc P on the driving disc S, will also vary uniformly with the twisting moment, if they are adjusted to their respective zeros when the springs are unloaded and free in both directions.

The work done in foot-pounds can be represented as the product of a constant C into the revolutions recorded by the integrating counter.

Let n = revolutions of integrating disc as recorded by its counter, then the foot-pounds of work done in any experiment $= C \times n$.

The constant C is usually determined by securing the shaft and fast pulley A, and loading the loose pulley B with a known weight W, suspended on one side by a small cord wound round its rim and attached elsewhere, the discs and other parts having been previously adjusted accurately. Then the clutch at V being disconnected, the registering apparatus is turned round by hand till any number of revolutions of the dynamometer is recorded by the counter T. Let N = such revolutions of dynamometer, c = circumference of pulley in ft., W = weight in lb. applied to its circumference, n = revolutions recorded by integrating counter when N is taken, then the foot-pounds of work may be represented by either of the expressions $N \times c \times W$, or $C \times n$. Therefore $N \times c \times W = C \times n$, and $C = \dfrac{N \times c \times W}{n}$.

The test should be repeated with increased loads, and should be applied at different parts of the circumference of B, to eliminate errors arising from lack of balance of the pulley B, and to determine whether any material correction K must be taken into account, in consequence of imperfect adjustment at starting.

In a 50 horse-power rotary dynamometer the chief difference from the 20 horse-power dynamometer is that it is provided with six straight radial springs attached to the projecting boss of the loose pulley B, and bearing against rollers projecting from the arms of the fast pulley A just within its rim. The springs are thin, flat-tapered plates, proportioned to act as cantilevers supported at the centre boss and loaded at the bearing rollers at their outer ends.

H. Darwin obviates the use of a spring, by employing a system of rods and a weight, which makes the distance of the integrating wheel from the centre of the large disc always proportional to the moment of the force turning the dynamometer. The principle of the arrangement is diagrammatically shown in Fig. 1082, where the line O G represents a rod capable of turning freely in the plane of the paper about the fixed point O; at G it is pivoted to the centre of a rod A G B, which is twice the length of O G. Then the point B being guided to move in the vertical line O B, the other end A of the rod will necessarily move in the horizontal line O A, in consequence of the property that the angle contained in a semicircle is a right angle; the principle of the ordinary grasshopper parallel motion. At B a weight W is suspended, and at A a horizontal force P acts, which is proportional to the moment turning the dynamometer. As the rod O G can turn freely at O, the reaction at G must be in the direction G O, when there is equilibrium; and as there are three forces acting on the rod A G B, two of which, the horizontal force P and the reaction at G, have their directions meeting at the point O, the direction of the third force must also pass through the same point O; that is to say, neglecting the weight of the rods, there will be no reaction between the end B and its guides. The directions of these three forces being parallel to the sides of the triangle O H G, their magnitudes are proportional to the length of its sides, and the force P varies as the tangent of the angle which the rod O G makes with the vertical, as W is a constant. The farther the point A moves from O, the greater P becomes; and when the rods O G and A B are vertical, P is nothing. If the rod G O be prolonged in a straight line beyond the fixed centre O, and F be its intersection with a horizontal line drawn through any point E in the vertical line E O B, the distance of F from E will vary as the tangent of the angle which O G makes with the vertical, and therefore as the force P. This force being proportional to the moment turning the dynamometer, if the small integrating wheel be made to move towards or from the centre of the disc as the point F moves towards or from E, the counter attached to the integrating wheel will register a number proportional to the work passing through the machine. The weights of the rods O G and A B, which have been neglected, will only have the effect of causing a slight reaction between the end B and its guides, and of adding a small amount to the weight W; and this will cause no error in the action of the machine constructed upon this principle.

1082.

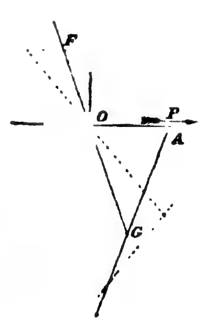
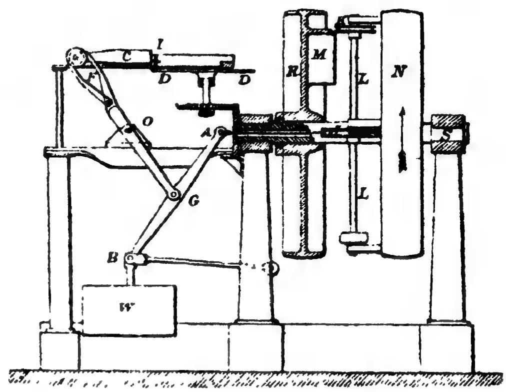


Fig. 1083 is of the rotary dynamometer designed on this principle; the only difference being

that the point B from which the weight is suspended, is guided in an arc of a circle by means of a radius rod of suitable length, as this causes less friction than a block sliding between guides, and will produce no sensible error. The counter C and integrating wheel I form a small carriage, the weight of which is supported at one end by the integrating wheel itself resting on the face of the large horizontal disc D, and causing sufficient pressure to produce rotation of the wheel when the disc rotates; and the other end of the carriage is supported by a pair of wheels running on horizontal rails. On the axle of these carrying wheels are two loose rollers, against each of which presses one arm of the fork F, on the end of the rod O G, and thus the carriage and integrating wheel are moved backwards and forwards as the fork moves; the arms of the fork are held together by a spring, so that no backlash can take place. The integrating wheel I is adjusted so as to be at the centre of the disc D, when the fork F and rod O G are vertical: hence its distance from the centre of the disc at any time is proportioned to the force P.

1083.



The pulley N, driven by a belt from the engine, is keyed upon the main shaft S, on which is also carried a loose pulley R of the same diameter, for driving the machine to be tested. The shaft S is made hollow, and inside it slides a flat iron bar, the outer end of which is connected to the end A of the rod A B by a swivel joint, allowing the bar to rotate with the shaft; the inner end of the bar is attached to a short chain, which is fastened to the circumference of the small wheel J, a slot being cut in the shaft S to admit the rim of the wheel for this purpose. The spindle L of the wheel J is supported by brackets bolted to the side of the fast pulley N; and on one end of the spindle is keyed another small wheel K, with a short chain fastened to its circumference, the other end of the chain being attached to a sector of a circle M cast on the side of the loose pulley R. The whole force that drives the loose pulley is thus transmitted through this chain, the tension of which is therefore proportional to the driving force; and this tension being communicated directly through the wheel J and the sliding bar to the point A, the distance of the integrating wheel from the centre of the disc D is proportional to the power driving the machine that is being tested.

The constant for this dynamometer has not to be determined every time the instrument is used; when once known it does not alter with use. It may be determined in the ordinary way by hanging known weights to the circumference of the loose pulley, and turning the disc D a known number of times, and then reading the counter; but it could probably be ascertained with greater accuracy by calculation, and it could be made equal to any convenient number by constructing the parts with proper dimensions.

In discussion upon this paper, F. J. Bramwell said a very simple mode of making rapidly a dynamometer, sufficient for the purpose of giving a rough estimate of the power exerted by a portable engine in doing any particular work, was to lay a leather friction strap over the driving pulley of the engine to be tried, to one end of which was attached the weight to be lifted, while the other end was fixed to an ordinary spring balance. The engine was then set to work to lift the weight, and supposing the gross weight suspended from the strap was 100 lb., and that when it was held up from the ground by the engine, the spring balance indicated 20 lb., then the effective weight lifted by the engine would be 80 lb. Suppose the friction increased and the band began to wind the weight up, so that the tension upon the spring was reduced to say 18 lb., then the effective weight would be 82 lb., and that would restore the balance of work. If on the other hand there was not friction enough, and the weight began to fall, the spiral spring would be extended and the effective weight would be lightened, because the spiral spring by its range of motion would take an increased portion of the strain, and thus cause a deduction from the weight at the other end of the strap.

Simple, effective, and convenient as the arrangement of the friction brake dynamometer is when employed on a small scale, it proves to involve serious difficulties.

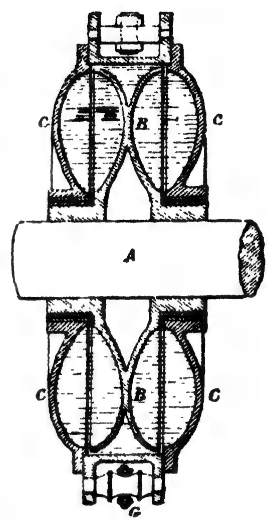
In a dynamometer for measuring the power delivered to the screws of large ships, W. Froude has designed that the reaction, instead of arising from the continuous friction of two solid surfaces, consists of a multitude of reactions supplied by the impact of a series of fluid jets or streams, which are maintained in a condition of intensified speed, by a sort of turbine revolving within a casing filled with water, both the turbine and the casing being mounted on the end of the screw shaft in place of the screw, the turbine revolving while the casing is dynamometrically held stationary. The jets are alternately dashed forward from projections in the turbine against counter projections in the interior of the casing, tending to impress forward rotation upon the casing, and are in turn dashed back from the projections in the casing against those in the turbine, tending to resist the turbine's rotation. The important point is that the speed of the jets is intensified by the reactions to which they are alternately subjected, and a total reaction of very great magnitude is maintained within a casing of comparatively very limited dimensions.

Figs. 1084, 1085, show what has been termed the turbine dynamometer; it is a disc or circular plate B B, with a central boss keyed to the screw shaft A in place of the screw, and revolving with the shaft. The disc is not flat throughout its entire zone, being shaped into a channel of semi-oval section, which sweeps round the whole circumference concentrically with the axis. To give defi-

niteness to the conception, let it be imagined that, to deal with an engine of 2000 indicator horse-power, the diameter of the turbine disc to the outer border of the channel is 5 ft.

The casing C C, has now to be added. The face is shaped into a channel, the counterpart of that in the turbine disc, which it fronts precisely, so that the two semi-oval channels in effect form one complete oval channel, though the two halves are in reality separated by an imaginary plane of division. The back of the casing embraces or includes the turbine entirely, but without touching it. The casing is also provided with a boss, which is an easy fit over that of the turbine; and thus the turbine carried by the shaft can revolve within the casing without touching it, while the casing itself is stationary. One half of the oval channel is running round while the other half is at rest.

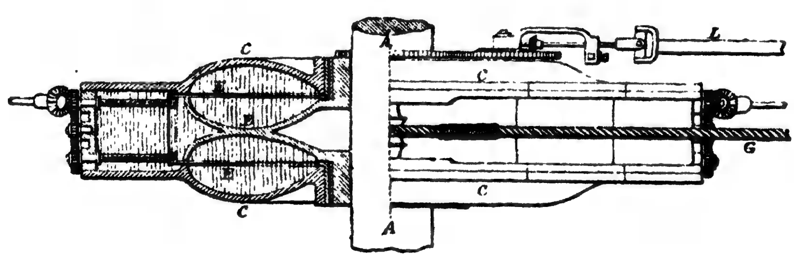
1084



Thus far the two half channels have been regarded as open and unobstructed; they are in fact each closed or cut across by a series of fixed diaphragms E E. The diaphragms cut the turbine channel, not perpendicularly, but obliquely, being semicircular in outline, so that when set obliquely their circular edges fit the oval bottom of the channel, while their diameters span the major axis of the oval. Each half channel has twelve of these diaphragms, and is divided into a series of cells, each of which, if viewed at right angles to one of the diaphragms, or if shown in a section taken parallel to one of them, is semicircular in outline; and if viewed in connection with the cell, which is for the moment opposite to it in the counterpart half channel, the two together make one complete cell with circular outline. Thus the whole oval channel may be regarded as a series of obliquely placed circular cells; and as the function of the turbine is to rotate while the casing remains at rest, one half of each cell is moving past the other in such a manner that the moving half, if viewed from its stationary counterpart, would by reason of the oblique direction of the diaphragms which form the cell sides, appear to be advancing antagonistically towards it. The motion virtually constitutes such an advance, because the bottom of each moving half cell is continually approaching the bottom of the stationary half cell which it faces. The effectiveness of this combination to resist rotation depends essentially on this virtual approach of the moving to the stationary half cells.

The channel and the whole casing is filled with water, and the turbine is made to rotate. When the turbine is thus put in motion, the water contained in each of its half cells is urged outwards by centrifugal force; and in obeying this impulse it forces inwards the water contained in the half cells of the stationary casing, and a continuous current is established; outward in the turbine half cells, inward in those of the casing.

The current, though originated solely by centrifugal force, possesses a power of growth independent of centrifugal force, and dependent on what has been termed the virtually antagonistic attitude or motion of the two sets of diaphragms, and the cells of which they are the boundaries.



The nature of this power of current-growth is somewhat intricate to trace. With any given speed of the turbine, the system of internal motions involves a potential or definite speed-producing power, which will continue to increase the speed of the currents until the friction experienced by them in traversing the cells, produces a resistance equal to the potential. This frictional resistance, as well as the potential itself, are alike proportioned to the square of the speed of the turbine, and the resulting speed of current is directly proportional to the speed of the turbine simply.

The manner in which the currents, when established, produce the dynamometric reaction, can be traced very easily. The explanation already given of the internal form of the cells which the current traverses, shows that the volume of water which constitutes the current in each complete cell, may be regarded as a circular plane or disc of water, rotating in its own plane between the diaphragms, which define the direction of the water disc and which are the boundaries of its thickness. As the diaphragms radiate from the centre of the turbine and casing, the discs of water which they enclose, will not be of parallel thickness throughout, the part furthest from the centre being thicker than that nearest to it; but if the breadth of the channel in the turbine, which the diaphragms close, is small compared with the distance of the channel from the centre of the turbine, and the diaphragms are close together, this inequality of thickness will disappear.

Each of these rotating circular water discs, may be regarded as consisting of a series of hoop-shaped pipes or tubes of infinitesimal thickness, laid one within the other, and each filled with a

stream of some appropriate speed, the sides of the pipes being merely imaginary boundaries. The disc, made up of these streams, will constitute a sort of vortex. Each vortex, in virtue of the centrifugal force which is continually tending to stretch it edgeways, pushes against its circumferential boundaries; and as these boundaries are made up of the bottoms or circular outlines of the two half cells occupied by the vortex, the resultant force measured in the plane of rotation of the turbine, is constantly tending, with a determinate force, to stop the rotation of the turbine, and to create rotation in the casing.

A simple way of expressing the magnitude of this force, is to regard it as due to the reversal, in each semi-revolution of the vortex, of the aggregate momentum of the vortex streams, measured in the plane of rotation of the turbine; for the streams which on entering the cell are flowing in one direction, are flowing in the opposite direction with precisely the same speed on leaving it, and the force due to the reversal, is directly proportionate to the amount of momentum reversed in a second. This is as the product of the mass acted on in a second, and the change of speed imparted to it in the plane of rotation of the turbine. The change of speed is twice the speed of the turbine. The mass acted on in a second is as the mean speed of the vortex current, which bears a constant relation to the speed of the turbine; so that the tendency of each vortex to stop the rotation of the turbine, and to give rotation to the casing, is as the square of the speed of the turbine.

This element of reaction would continue to act for a time, even if the turbine were suddenly brought to rest; for the vortical rotation to which it is due would continue, though with gradually diminishing speed, until it was extinguished by friction. But there remains another element of reaction to be taken account of, which exists only while the turbine is in rotation.

This is due to the circumstance that the imaginary hoop-shaped streams, of which each vortex is made up, are perpetually being severed or sheared, by the passage of the planes of the turbine diaphragms past those of the casing diaphragms. The action here referred to does not interrupt or alter the effective speed of the streams thus displaced, for these, in virtue of the incompressibility of water, must each traverse its imaginary pipe everywhere with the same speed; but in virtue of the action, the particles which constitute each stream must, at the points of shearing, be perpetually undergoing alternate changes of speed, backwards and forwards in the plane of rotation of the turbine. For as they pass from the stationary casing cells to the rotating turbine cells, they are obliged to assume the speed of the turbine in its plane of rotation, and they thus react on the turbine diaphragms with a definite force, due to the amount of momentum a second imparted to them in transition. Again, as they pass from the rotating turbine cells to the stationary casing cells, they are obliged to lose that speed in the plane of the turbine's rotation, and they thus act on the casing cells, tending to push them forward, with the same force with which their reaction tended to push back or stop the rotation of the turbine cells. The force is the same, because the same mass a second is acted on in both instances, and the same speed is in the one instance imparted, in the other instance taken away.

The reaction is as the square of the speed of turbine rotation, since the momentum generated a second is as the product of the mass operated on in a second and the speed imparted to it. The speed imparted is simply the speed of the turbine, and the mass operated on is as the speed of vortical rotation, which is necessarily as the speed of the turbine.

It is necessary to show that an adequate amount of total reaction can be produced by an instrument of conveniently limited dimensions; and that an instrument of given dimensions is governable as regards its reactions, that is, capable of being made to produce at pleasure a greater or less reaction with a given number of revolutions, so that within reasonable limits the same instrument is capable of dealing with engines of great or small power, allowing each to make its proper number of revolutions.

As regards the first condition, theory shows that, comparing two strictly similar but differently dimensioned instruments, their respective movements of reaction, with the same speed of rotation in each, should be as the fifth powers of their dimensions. This proposition is fully borne out by experiment. A pair of similar instruments were made, in which the turbine diameters are respectively 12 in. and 9·1 in. Now $\left(\frac{12}{9\cdot1}\right)^5 = 4$, and accordingly the ratio of the moments of the two instruments at a given speed of turbine rotation should also have been 4. The ratio was in fact 3·86: but the small difference is referable to the circumstance, that in the larger of the two instruments the internal surface was rather less smooth, and the friction of the water consequently rather greater than in the other. The data thus obtained not only verify the scale of comparison based on the 5th power of the dimension, but they also furnish a starting point, by which to obtain the dimensions of the instrument which will be required to deal with any given horse-power, delivered with a certain number of revolutions a minute. It appears that to command the measurement of 2000 horse-power delivered with 90 revolutions a minute, a fairly typical speed for the power, an instrument is required with the turbine 5 ft. in diameter, and being in fact a duplicate turbine, or formed with two faces, with a double-sided casing to match. This two-faced arrangement, while it supplies a double circumferential reaction with a given diameter, has the advantage of obliterating all mutual thrust on the working parts; the centrifugal forces of the double set of vortices pressing with equal intensity on the two internal opposite faces of the rigid casing.

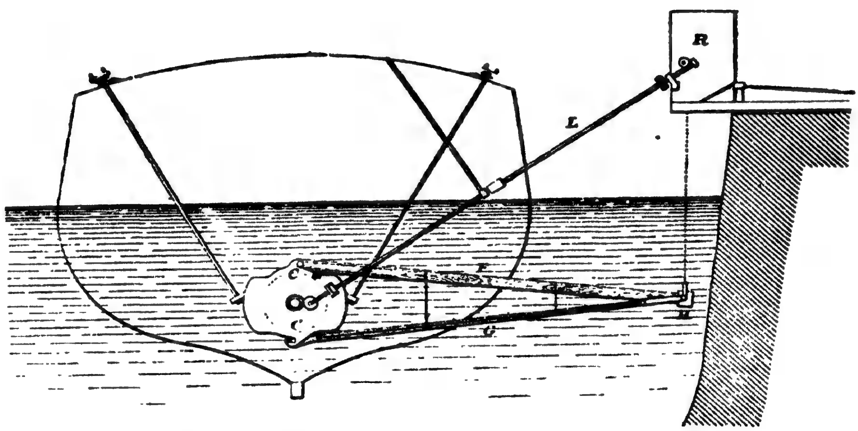
As regards the second condition, theory suggests that, by contracting the internal waterways, that is to say, the passages through the cells in the turbine and the casing, and intercepting the free vortical rotation, the moment of reaction due to a given speed of rotation could be greatly reduced. Experiments fully bear out this anticipation. The reaction with any given speed of turbine rotation can be reduced with a perfectly graduated progression, in any required ratio, down to 1-14th; the object being effected by advancing, from recesses in the casing, abreast of the two opposite quadrants in each turbine, a lunette-shaped sliding shutter of thin metal, so fitted as to be carried forward along the divisional plane between the turbine cells and the casing cells. The

intensity of the reaction is thus brought completely and easily under command; and in virtue of it, it follows that the instrument, which, as already stated, is capable of dealing with an engine of 2000 horse-power making 90 revolutions a minute, is also capable of dealing with one of only 340 horse-power making 120 revolutions a minute. As it happens that the reaction of the instrument varies as the square of its speed of rotation, and the horse-power delivered through it consequently varies as the cube of the speed of rotation, it follows that the same setting of the shutters which suits a given engine when working with its highest speed and power, will also approximately suit it when eased down to its lowest.

It seems therefore that, alike as to the dimension of instrument suited to engines of very high power, and as to the adaptability of a given instrument to engines of greatly varied power, the requisite conditions are satisfactorily fulfilled.

Having thus shown how the moment of rotation of the screw shaft is wholly communicated to the casing, which is to be dynamometrically prevented from rotating, and is thus to subject the engine to a restraint equivalent to that of obliging it to wind up a weight out of a well of indefinite depth, it remains to be explained in detail how it is proposed to carry out the operation in dealing with any given ship.

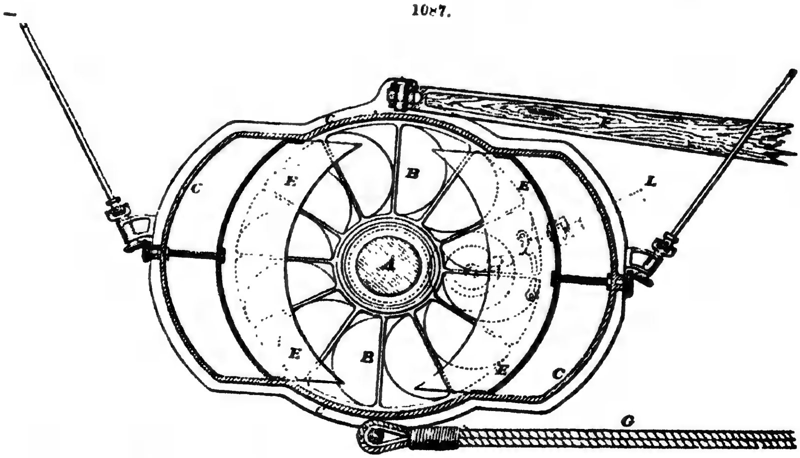
In order to render it easy to connect the instrument with any given screw shaft, the boss of the turbine must be bored out to a diameter considerably larger than that of the largest shaft to



which it can have to be applied; and, to fit it to a given shaft, an internal collar must be prepared, which will fit externally the interior of the turbine boss and internally the exterior of the screw shaft; and a proper keyway will be required for each fitting. The turbine thus mounted will run true on the screw shaft.

The ship, before she leaves the dock for the trial of her machinery, will have the instrument mounted as described, in place of her screw, Fig. 1086. The casing will be provided with proper

1087.



apertures, capable of being closed at will, to permit the egress of air and the ingress of water as the dock fills. The casing will thus be in a condition to receive the moment of rotation delivered by the screw, and to communicate it to the recording apparatus.

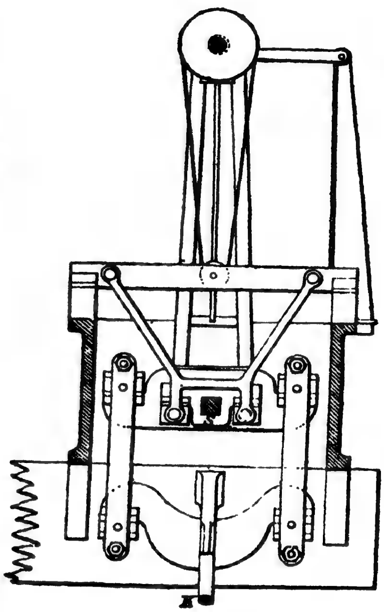
If the moment to be recorded is regarded as a product of two factors, force and leverage, of

which the one must vary inversely as the other, it is a question to be settled by considerations of convenience, whether the record shall take the shape of a large force delivered at short leverage, or the reverse; the force factor will prove inconveniently large, if taken account of at the circumference of the casing, and it is desirable for several reasons that it should be obliged to develope itself at a leverage enlarged to many times the radius of the casing.

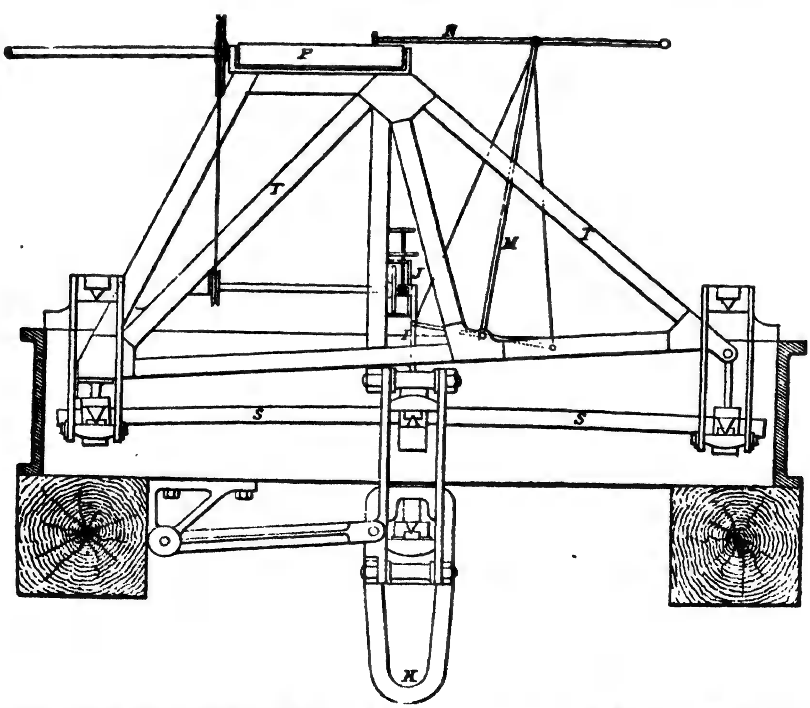
The assumed maximum which the instrument described was calculated to deal with, was stated to be 2000 horse-power delivered at 90 revolutions a minute; and this, if taken account of at the circumference of the casing, say at 3 ft. from the centre of the screw shaft, would take the shape of a circumferential strain of 17·4 tons, a force which will bear large reduction; and it is proposed to effect this by the arrangement shown in Fig. 1087, which by lengthening the leverage in the ratio of 10 to 1, reduces the force in the same proportion. The lever here shown is a triangular combination, of which the diameter of the casing C C armed with proper projections forms the base, while the two sides, the upper one of which will be always in compression and the under one always in tension, are a spar F and a wire rope G. When the screw shaft is rotating, the compression and tension of the sides will be 8·7 tons, and the downward force at the apex H of the triangle will be 1·74 tons or 3890 lb.

The lever will be fixed to the casing before the dock is filled, and its construction is such that it can be slewed and topped under the ship's quarter so as to swing clear of the dock walls. The ship thus fitted will be brought alongside some quay wall of one of the floating basins where the recording apparatus R, Fig. 1086, will have been already placed, projecting a few feet over the wall, and carried on strong cantilevers or brackets; and she will be secured head and stern so as to prevent fore-and-aft movement, and will be boomed off to a proper distance from the apparatus.

1088.



1089.

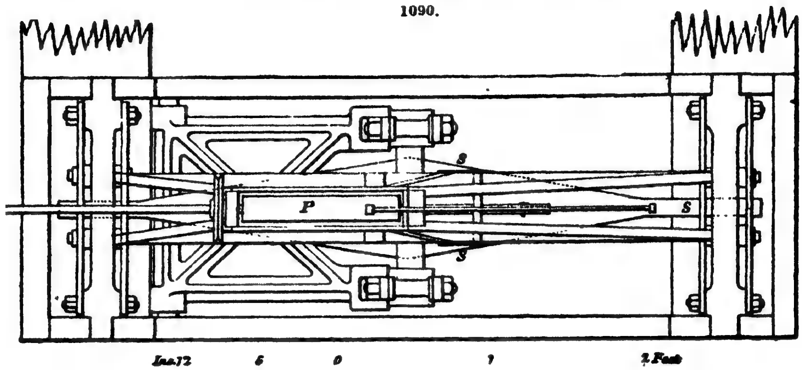


The arrangement of the dynamometric apparatus presents no difficulty. The form shown in Figs. 1088 to 1090, has been carefully considered. In this, the downward pull delivered at K by the lever operates vertically on the middle of a flat horizontal steel spring S S, which is supported at both ends; and the spring is so proportioned that its maximum deflection shall be about 1½ in.

Different springs would be required for engines if of widely different power. Immediately over the spring will stand a light framework, carrying two independent types of recording gear, both of which will, however, be actuated by the upper end of one and the same feeler or sliding vertical rod I, Fig. 1089, which will convey to them the vertical elastication of the middle point of the spring, on which point its foot rests.

Under one type the feeler will govern the position of an integrating wheel J, Fig. 1089, working on the face of a rotating disc. The rotation of the disc will be made proportionate to that of the

1090.



screw shaft, being communicated by a telescopic universal jointed spindle L, Fig. 1087, which takes its motion from the shaft by bevel gearing. When there is no stress on the lever, and no deflection of the spring, the integrating wheel will be adjusted to touch the disc at its centre, and thus will receive no rotation, and its count will be zero, whatever be the speed of rotation of the disc. When the spring is strained by the lever, the departure of the integrating wheel from the disc centre will be proportioned to the strain, and its rotation and its count will be the product of the strain and the rotation speed of the disc, or, in other words, the product of the moment impressed by the screw shaft on the casing and the speed of the screw shaft; that is, the work done by the shaft.

With another type, the duty of the feeler I, Fig. 1089, is to actuate the horizontal arm of a light bell crank M, the vertical arm of which, by means of a long horizontal connecting rod N, carries a pen freely along a horizontal straight line, while a sheet of continuous paper P is independently moved under the pen across the line of its travel. The motion of the paper, like that of the rotating disc, will be derived from the rotation of the screw shaft. A stationary companion pen will trace on the paper a straight line as a record of that which the moving pen would trace if the spring remained unstrained, and will serve as a zero of force. The moving pen will trace a diagram, the ordinate of which is at each instant a measure of the strain on the spring, and the area of which, like the count of the integrating wheel, is the product of the moment on the casing and the speed of the screw shaft; or the work delivered by the screw shaft.

In order that the indications of the pointer may represent with strict accuracy the elastications of the spring, and nothing else, the light framework T, Fig. 1089, which carries the integrating apparatus, and serves as the gauge from which the deflections of the spring are measured, will have its footing, not on the main frame, but on the spring itself immediately over its points of support. Thus, as the light framework T is itself subject to no strain, and may be made extremely rigid, the apparatus will precisely record the motions of the spring alone, however the main frame may be strained.

The connections of the dynamometer spring, with its framework and lever, are all arranged with mechanical details, such as to eliminate the effects of oblique stress, should any be introduced, by slight motions of the ship.

While a dynamometric trial is in progress, a series of indicator diagrams should be taken at short intervals of time; a comparison between the indicated horse-power as determined by these, and the delivered horse-power as determined by the dynamometer, would show how much power is wasted in the working of the machinery between the cylinders and the end of the screw shaft. The waste thus measured would be on precisely the same footing as that which would subsist while the engines were propelling the ship under the same indicated horse-power, except as regards two particulars; the friction due to the thrust of the screw; the difference of friction in the bearings which carry the screw shaft, between that due to the weight of the screw on the one hand, and on the other to the weight of the turbine and casing substituted for the screw, coupled with the side strain of the lever, which, whatever it be, is a lifting strain tending to diminish the effective weight of the turbine and casing just mentioned. It will not be difficult to apply a calculated correction to the effect of both these circumstances.

It is superfluous to recapitulate in detail the advantages which could be derived from the system of subjecting marine engines to dynamometric trial. The chief difficulties which arise are that the speed attained by a given ship, driven by a given indicated horse-power, fails to measure discriminately the merits of the ship; no means exist of ascertaining which type of engine delivers the largest proportion of the power that it indicates; no test exists by which it is possible to measure concisely the specific constructional merit of this or that engine, or to determine the relative constructional merit of the engines supplied by different firms.

The dynamometric test would remove at once each of these difficulties, by substituting a final and real test for a collateral and to a large extent a delusive one. For to rely exclusively on the test furnished by the indicator is almost equivalent to testing the power of a horse solely by the quantity of food he consumes and digests, or the efficiency of a boiler solely by the quantity of coal an hour it will legitimately consume on its firebars.

To trace the dynamic actions which are correlative to the internal fluid motions of this marine dynamometer, it will be convenient to recur to the notion of the discs of water, and to regard the channel as virtually straight and of unlimited length.

Remembering that the cross section of the channel is elliptical, each of these vortex discs may be assumed to be subdivided by a series of quasi-elliptical layers or skins, laid conformably to the inner surface of the channel, and obliquely intersected by a series of planes laid parallel to the diaphragms; and these surfaces to be rigid but without thickness, and frictionless.

Then the spaces between every pair of diaphragms in the turbine, as well as those in the casing, would be regarded as completely occupied by a honeycomb system of pipes, of parallelogram section, and of a semicircular outline when referred to the planes of the diaphragms.

When the turbine is at rest, each of the imaginary pipes may be regarded as capable of carrying a complete circular ring of water, flowing round this single circuit, with uniform speed. When the turbine is in motion, it is not delivering back its water into the reverse of the counterpart of the turbine-pipe from which it was received, thus forming an independent ring, but the water received from one pipe, is presently discharged into the mouth of some other, with which it happens to be brought into connection by the motion of the turbine.

Let the speed of the turbine and that of the flow relatively to the pipes be respectively represented by two geometric components, then the compound speed of the particles, that is, their actual speed in space as they issue from the turbine pipes, is shown by the resultant. It will be convenient to call the speed and direction of the streams as indicated by the component, their established speed, and established direction; and as indicated by the resultant, their augmented or compound speed and compound direction. These speeds will subsequently be denoted by the letters V, v_0, and v_1, respectively.

It is obvious that, measured relatively to their compound direction, the streams all become diminished in width or in sectional area, precisely as their speed is augmented; and again, that on entering the stationary pipes, the streams are obliged to resume at once their established direction and their established speed.

The loss of speed is of necessity accompanied by an exaltation of pressure in the mouths of the recipient pipes, and the enforced change in direction of flow, involves a definite forward force on the sides of the recipient pipes which causes the deflection. This local augmentation of pressure, being satisfied in one direction, by the retardation it imposes on the particles which are approaching it from behind, satisfies itself in the other direction by acting as a definite force, urging forward the flow of the streams, and maintaining their speed in spite of frictional resistance; and constitutes what has been termed the potential.

The problem, reduced to its essential features, may be stated as follows. A stream with the speed v, in feet a second, which corresponds with what has been termed the augmented speed, and under zero pressure or atmospheric pressure, enters a bent pipe, with a definite direction and completely filling the pipe entrance; in passing an enlargement in the pipe it assumes the reduced speed v_0, which corresponds with what has been termed the established speed, and which is less than v_1 in the inverse ratio of the pipe areas at the two positions; and flowing with that reduced speed through the enlarged pipe and experiencing frictional resistance in its flow, it issues in a direction different from that in which it entered and having again assumed the atmospheric pressure. The questions to be answered are, What external or displacing force does the stream exert on the pipe, and into what internal force tending to overcome the friction of the flow, is the suppressed speed, $v_1 - v_0$, transmuted? The two branches of the question may be answered independently.

As regards the external or displacing force, each end of the stream will exert an appropriate push on the pipe, that at the entrance forwards and at the outlet backwards. If W be the weight in lb. of water passing a second, the respective equivalent forces are $\frac{W v_1}{g}$ and $\frac{W v_0}{g}$; the total displacing force experienced by the pipe being the resultant of these two forces.

As regards the internal propulsive force, or potential, which maintains the speed of flow in spite of friction, it is well known that if the pressure of the water on each unit area be zero at the point of greatest contraction and of highest speed, say v_1, and that if P_1 be the pressure due to, or which would generate, a flow of that speed, then where the stream has become enlarged so that its speed is reduced to zero, the water will have assumed the pressure P_1. If, however, the enlargement be only such that the speed is reduced, not to zero, but to v_0, the pressure will have increased, not to P_1, but to a pressure, say P, which falls short of P_1 by the pressure, say P_0, due to the reduced speed v_0, and bearing to P_1 the ratio of v_0^2 to v_1^2, in fact $= \frac{v_0^2}{v_1^2}$, so that $P = P_1 = P_0 = P \left(1 - \frac{v_0^2}{v_1^2}\right)$. Now, as the water will have resumed the zero pressure on reaching the outlet, the potential is the pressure P acting on the whole sectional area of the pipe as enlarged from a_1 to a_0; and $F = P a_0 = P_1 \left(1 = \frac{v_0^2}{v_1^2}\right) a_0$.

A provisional solution is attainable, in relation to any given layer of streams, at a given distance from the vortex-centre, by assigning an arbitrary value to the friction, assuming it to be approxi-

mately as the square of the speed of flow, so that $F = \frac{W}{2 g v_0}(V^2 + 2 V v_0 \sin. \beta_0)$, where β_0 is the angle made by the component.

Now F is repeated twice in each complete circuit round the channel, once at the passage from the turbine pipe to the casing pipe, and once the reverse way. So that, for the complete potential due to the circuit, we may put $F' = \frac{W}{g v_0}(V^2 + 2 V v_0 \sin. \beta^0)$.

These two equations establish a coherence and consistency in the solution as follows. The whole work or energy employed in driving the turbine must go either into the acceleration of the streams before the steady flow is established, coupled with the work of friction due to the existing flow; or ultimately into work of friction simply; and in either case the work done by the potential upon acceleration and friction should equal the work done in driving the turbine, and the comparison is now easily made.

Calling the work a second, in driving the turbine, U_Φ,

$$U_\Phi = \Phi V = \frac{W}{g}(V^2 + 2 V v_0 \sin. \beta_0).$$

Calling the work done by the potential, U_F,

$$U_F = F' v_0 = \frac{W}{g}(V^2 + 2 V v_0 \sin. \beta_0).$$

The two values are, as they ought to be, identical. But further, by assuming a coefficient of fluid friction, of the form $= f v^2$, the relation is established which will subsist between V and v_0 when the friction has become equal to the potential.

In this case

$$f v_0^2 = F' = \frac{W}{g v_0}(V^2 + 2 V v_0 \sin. \beta_0),$$

the solution of which, observing that $W = w a_0 v_0$, is

$$\frac{V}{v_0} = \sqrt{\frac{g f}{w a_0} + \sin.^2 \beta_0} - \sin. \beta_0, \qquad (3)$$

so that in any given pipe $\frac{V}{v_0}$ is constant.

From this it follows that, if each of the imaginary pipes had real sides by which the friction operated, the speed of flow could be defined at the various distances from the vortex centre. For suppose the girth of each pipe to be the same, say k, then its length would be as its distance centre, say $l = 2 \pi r$; and substituting for $f v_0^2, f' \times 2 \pi r k v_0^2$, f' being the co-efficient of friction for unit area at unit speed,

$$\frac{V}{v_0} = \sqrt{\frac{2 \pi f' \pi r k g}{w a^0} + \sin.^2 \beta_0} - \sin. \beta_0,$$

so that the speed in each pipe would be an inverse function of its distance from the vortex centre.

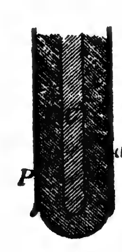
In explanation of what had been spoken of as the power of current growth in the cells of the dynamometer, suppose a jet of water were issuing from a nozzle with a velocity of 10 ft. a second, and that it were caught by a fixed bent tube of the same bore as the jet, and bent to a semicircle; then the water would evidently enter the bent tube with a velocity of 10 ft. a second, and be discharged with the same velocity, while in passing round the bend it would in virtue of centrifugal force exert a pressure tending to move the bend away from the jet. Now supposing the bent tube, instead of being fixed, were made to move at the rate of 1 ft. a second, or to approach the issuing jet at that speed; then the water, instead of entering the bend at 10 ft. a second, would enter it at 11 ft. a second relatively to the bend, and would pass round the bend at this velocity, finally escaping with a velocity of 11 ft. a second relatively to the bend, but of 12 ft. a second relatively to any fixed point. Thus, a forward motion of the bend at the rate of 1 ft. a second would result in accelerating the current of water at the overflow by 2 ft. a second. If, now, the issuing water entered a fixed semicircular bend, it would traverse this bend at 12 ft. a second, and on issuing from this fixed bend at 12 ft. a second might be further accelerated by being passed through a second moving bend; and so on, assuming that no frictional or other resistances existed. The moving bend in this illustration might be considered to represent one of the half-cells in the turbine or moving portion of the dynamometer; and owing to the oblique position of the dividing diaphragms, the half-cells in the rotating turbine might be considered to be constantly approaching those in the fixed casing, so that the water on its discharge from the casing cells into the turbine cells underwent an acceleration which became continually augmented, until the frictional resistance encountered in traversing the cells was equal to the speed-producing power. The resistance to the rotation of the turbine consisted in the resultant, in the place of rotation, of the centrifugal force exerted by the current when traversing the curved contour of the cells in the turbine; this resistance, of course, is equal to the force exerted in the opposite direction upon the cells of the fixed casing.

ELECTRICAL ENGINEERING.

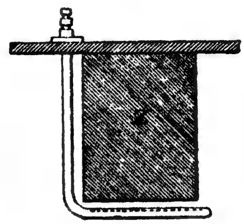
The principal forms of batteries used in electrical engineering will be found described at page 226 of this Dictionary. Very minor improvements have been made in this branch of electrical science, if there be excepted Byrne's compound-plate battery which is specially known as the pneumatic battery. The chief feature of this battery consists in the negative plate, which, instead of being of one material, is constructed of three metals soldered together. The surface exposed to the exciting solution and

opposed to the positive or zinc plate, is platinum, P, Fig. 1091, backed by and soldered to a plate of sheet lead L. Behind this lead is a plate of copper C′ backed by another sheet of lead, or fold of the first lead plate doubled on to the back of the copper. The outside or back surface of this second layer of lead is coated with asphaltum varnish *a*. Fig. 1091 is a vertical cross section of the compound negative plate in which the thickness of its laminæ are exaggerated in order to show its construction. The copper plate C′ is completely enveloped by the lead L, both with regard to its face and edges, so that the copper core is in no way exposed to the exciting solution of the battery. The total thickness of the compound plate does not exceed one-eighth of an inch; the lead weighs 8 oz. to the square foot, and the thickness of the platinum P is one two-thousandth of an inch. Each cell contains a central zinc plate Z, Fig. 1092, placed between two of the compound plates described, C C, Fig. 1093, the disposition of the plates being similar to that adopted in Wollaston's battery.

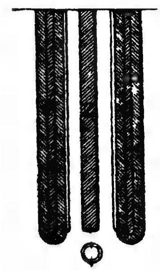
1091.



1092.



1093.



The exciting solution is similar to that used in the ordinary bichromate or Poggendorff battery, 5 oz. of potassium bichromate dissolved in 5 pints of boiling water, to which is slowly added, when cold, 1 pint strong sulphuric acid. In the pneumatic form of the compound-plate battery, the exciting solution is kept in a state of mechanical agitation, by air being pumped into the cells through an ebonite tube, leading from each cell-cover to the bottom of the cell, where it turns at right angles, so as to lie in a horizontal position underneath and in a line with the central zinc plate, and between the compound plates. The horizontal portion of this tube is perforated by two rows of small holes, one on each side of the middle line of its upper surface, and through these holes, when the apparatus is in action, jets of air are injected into the cell, which, rising in the form of bubbles between the plates, keeps the solution in violent agitation, washing off from the plates bubbles of hydrogen which otherwise would collect, and insuring fresh fluid being continually brought into contact with the plates. The air tube, Fig. 1092, terminates above the cover in a nozzle, to which is attached a vulcanized tube leading to a small hand syringe or bellows. Pumping in air has the effect of increasing the strength of the current, at the same time causes the temperature of the cell to be greatly raised, so that if the action be continued sufficiently long the solution will commence to boil.

1094.

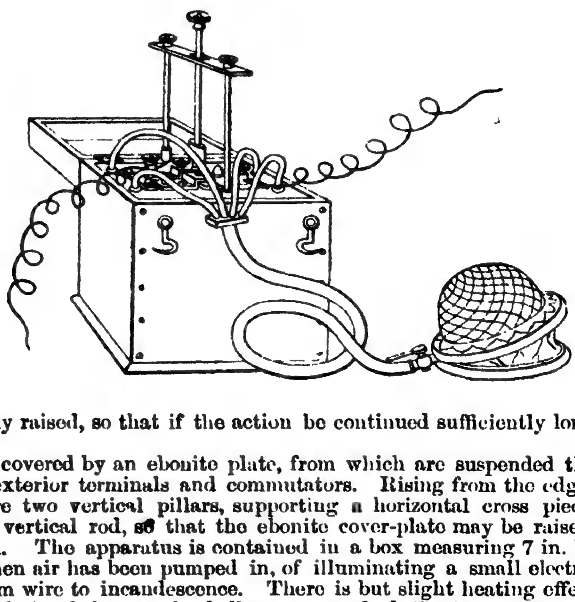


Fig. 1094 is a battery of four cells covered by an ebonite plate, from which are suspended the plates, and to which are attached the exterior terminals and commutators. Rising from the edges of the box containing the battery are two vertical pillars, supporting a horizontal cross piece, through the middle of which passes a vertical rod, so that the ebonite cover-plate may be raised, and the plates lifted out of the solution. The apparatus is contained in a box measuring 7 in. by 4 in., by 6 in. deep. It is capable, when air has been pumped in, of illuminating a small electric lamp, and of heating 8 in. of platinum wire to incandescence. There is but slight heating effect upon the platinum wire before air is admitted, but as the bellows are worked, the temperature of the wire rapidly rises to a brilliant red heat, and cools when the air injection is cut off.

The cauterizing apparatus is a surgical instrument, constructed of some insulating material, and carrying at its extremity either a loop, or a straight piece of platinum in the form of wire or of a flat band, according to the requirements of the case, which, by being brought into the circuit of the battery by means of insulated conductors passing down the stem of the instrument, can be made white hot, and the cauterizing operation performed.

Larger forms of apparatus for showing more powerful effects consist of ten cells, and when air is pumped in will heat to incandescence 36 in. of stout platinum wire, and decompose acidulated water at the rate of producing 16 cub. in. of gas a minute. This battery charges to its fullest extent an induction coil, giving sparks in air 18 in. in length while air is pumped in, falling to 8 in. when the air supply is removed.

A modification of Byrne's compound-plate battery for driving machines by means of electro-magnetic engines, or for electro-plating and other chemical applications, is the Motor battery by the same inventor. In the Motor battery there are but two plates to each cell, one compound plate and one of zinc, and the exciting solution employed is sulphuric acid diluted with nine times its bulk of water. As there is no occasion for the blowing apparatus, the platinum face of the com-

pound plate is platinized, adherent hydrogen being thus got rid of. Byrne states that eight cells of this battery are sufficient to drive a Singer sewing machine.

For plating purposes four cells of Byrne's Motor battery, containing plates of 20 sq. in. of surface, measuring 5 in. by 4 in., is more effective than six cells of Smee's battery, with plates having a surface of 60 sq. in.

Simultaneous Transmission.—When J. B. Stearns, of Boston, commenced his experiments in simultaneous transmission in 1868, very little was known in America respecting the previous labours of European electricians. Stearns improved on the Siemens-Halske method; that which had given the best results in practice. During 1872 improvements were added to Stearns's system which led to its immediate adoption upon many of the most important lines in the United States. The general principle of Stearns's apparatus does not differ materially from that of Frischen. In Fig. 1095 the key is replaced by a transmitter T, which is controlled by a key K, a local battery and an electro-magnet *t*. The principal object in introducing this modification was to adapt the system to the use of the American operator, who is accustomed to hearing the accompaniment of his own sounder when transmitting. The transmitter acts upon exactly the same principle as Nystrom's key, the contact of the battery with the line being made before the contact between the latter and the earth is interrupted. The resistance X in the artificial line is made equal to that of the main line. When the key K is depressed, the circuit of the local battery is closed, the electro-magnet *t* attracts its armature, operating the transmitter T, which first makes contact at *a*, and almost at the same instant lifts the contact lever, which is pivoted, and breaks contact at *c*. The current from battery B now goes by way of the transmitter T, and thence through *a* and *b* to the point *d*, where it divides into two equal portions, one going through the right-hand coil of the differential relay R to the line L, and thence to the earth at the distant station, and the other by way of the left-hand coil of the relay through the rheostat X, and thence directly to the earth. As these two branches or divisions of the current are equal and opposite in their effects upon the relay R, it will not respond. The incoming currents from the distant station, on the contrary, pass only through the right-hand coil of the relay R, and thence find their way from *d* to the earth by way of *c* and *x*, or else by *a*, T, B and *y*, the route depending upon the position of the transmitter. The resistance *y* is termed the spark coil, and is only required when a battery of small internal resistance is used, in which case the spark caused by the momentary short circuiting of the battery at *a c* would otherwise cause some embarrassment. The resistance *x* is made equal to the resistance of the battery, added to that of the spark coil in case the latter is used, and thus the incoming current always meets with exactly the same resistance, irrespective of the route by which it passes from the point *d* to the earth at E.

The diagram Fig. 1096, represents the arrangement at a terminal office. The continuous lines represent the main wires, and the dotted lines the local wires. K K' are keys in a local circuit which operates the transmitter T. L L' are local batteries. M is a main battery, G, earth, S, common Morse sounder; R *h*, rheostat; C, condenser; R, duplex relay; *t t'* are binding posts connected with the adjustable resistance coils; *r r'* are the terminals of small resistance coils, used for maintaining an equal resistance when line is to earth through battery, or to earth direct. The plugs in the resistance coils must be removed until the resistance of the coils equals the resistance of the line. When they are equal, the armature of the relay will not be affected by the working of the transmitting sounder. The object of the condenser is to receive a charge from the main battery equal to that entering the line, which charge being returned through the relay coil connected with the rheostat, at the same time that the line returns its charge through the other coil, neutralizes its effect upon the armature. The small resistance coils represented in Fig. 1096, as being enclosed in the box containing rheostat *Rh*, at r and *r'*, are generally enclosed in separate boxes.

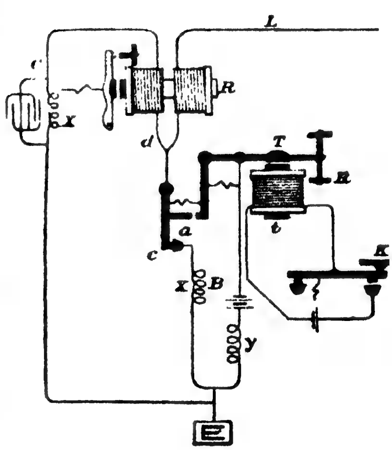
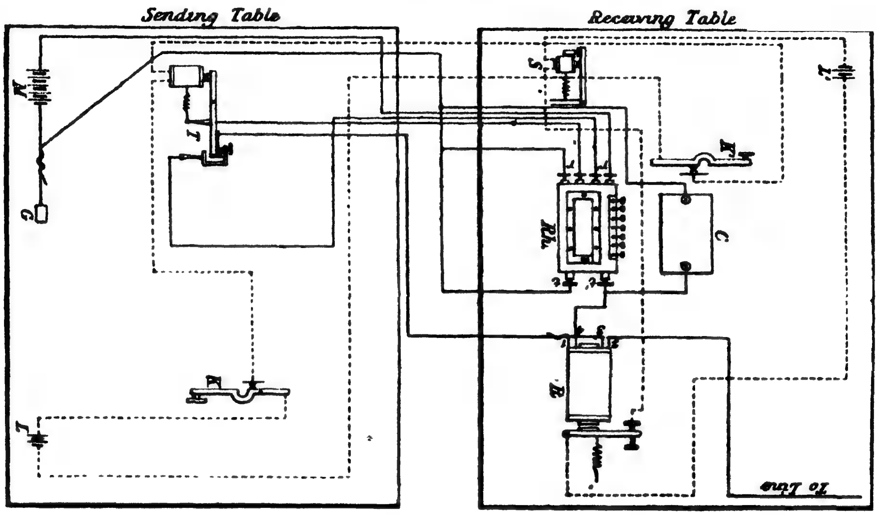


Fig. 1097 is a diagram of the connections representing a terminal station A, and an intermediate station C, on M. G. Farmer's duplex system, of which there may be any required number. It is only necessary to describe the arrangement at the terminal station A. The relay is provided with two coils, *r* and r_1, which are so wound as to assist instead of opposing each other, as in Frischen's plan. The coil r_1 contains about twice as many convolutions of wire as the coil *r*, or it may be otherwise arranged; the object being that with a given current the coil r_1 shall exert twice the magnetic effect upon the relay that the coil *r* does. The line wire which enters the station is divided into two branches at K, one branch going directly to the earth by way of 2 and 1, passing through the coil r_1, and the other by way of K, 3 and 4, passing through the coil *r*. For transferring the incoming current from one of these branches to the other, Farmer employed a continuity preserving key K *k* upon the same principle as that used by Nystrom in 1855. When the apparatus is in a position of rest, the route of the incoming current is by way of 2, r_1 and 1 to the earth at E. If the key K is depressed, the circuit of the main battery is closed, by the contact of its rear end with the supplementary contact lever *k*, which is at the same time lifted from the point 2. The outgoing current now passes through the coil *r* of the relay at the home station, and through the coil r_1 at the distant station. As the coil r_1 produces quite as great a magnetic effect upon the relay R as the coil *r*, it is easy to so adjust the respective relays that the distant one shall attract its armature, while

that at the home station remains unaffected. When both keys are depressed, the circuit is through the coil r at each station, but the effect upon each relay is doubled, because the line is traversed by the combined current of two batteries. In order to render it certain that the receiving instrument at the home station should remain unaffected by the outgoing current, Farmer made use of the device employed by Gintl in 1855; an adjustable rheostat X placed in a branch circuit or

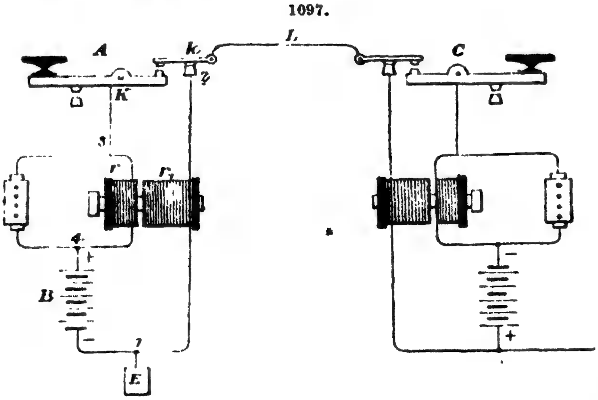
1096.



shunt passing around the receiving instrument, by which means so much of the outgoing current can be made to pass through the shunt, that the remaining portion will not be sufficient to produce any effect upon the receiving instrument.

The method of inserting any required number of intermediate stations, devised by Farmer in connection with this invention, is represented at C, in Fig. 1097. The only variation from the ordinary arrangement of a terminal station consists in connecting the line wire running in one direction in the place of the earth wire. When the key is depressed at the intermediate station, the relays of both terminal stations respond, as the battery current traverses the entire line. This arrangement is of course applicable to any other similar method.

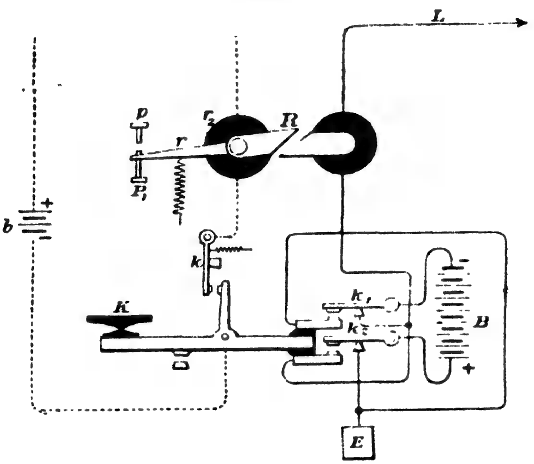
1097.



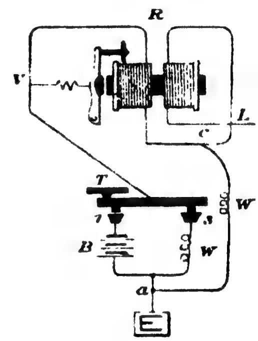
The diagram, Fig, 1098, illustrates the principle of another method by Farmer. The key K, when depressed simultaneously lifts three separate contact levers k, k_1, k_2. The contact levers k_1 and k_2 are so connected with the main battery B, line wire L, and earth E, that the depression of the key has the effect of interchanging the poles of the main battery, with respect to the line and earth wires, or in other words, of reversing the current upon the line. This reversal is effected without at any time interrupting the continuity of the main circuit. The relay R is constructed with two separate coils, r_1 and r_2, the former being included in the main circuit, between the key and the earth, and the latter in the circuit of a local or equating battery b, by the contact lever k, whenever the key is depressed, at the same instant that the battery is reversed upon the main line. The cores of the two coils of the relay are provided with bevelled pole pieces, which are so arranged that they act as armatures to each other. The core of r_1 is fixed, while that of r_2 turns upon its axis, the arm r which opens and closes the local circuit of the register or

sounder, being attached rigidly. When the poles of the two magnets r_1 and r_2 attract each other, the arm r is pressed against the stop p, and the local circuit is closed, but when the attraction ceases, or is succeeded by a repulsive action, the spiral spring acts, drawing down the arm r opening the local circuit. The action of the apparatus is as follows,—The main batteries B at the two terminal stations are preferably arranged with their negative poles to the line, as shown in Fig 1098. In the normal position of the apparatus these neutralize each other, and there is no attraction between the poles of the magnets r_1 and r_2 of the relay R. If now the key K is depressed, the battery B at the home station is reversed; its polarity then coincides with that of the battery at the distant station, and the combined current of both batteries traverses the line, producing a corresponding magnetic effect in the coil r_1; at the same instant the equating circuit is closed at k, and the current of the equating battery b, traverses the other coil r_2, giving it an equal and opposite magnetic polarity, in consequence of which the home relay is unaffected by the depression of the key at the same station. When the key at the remote station is depressed, and

1098.



1099.



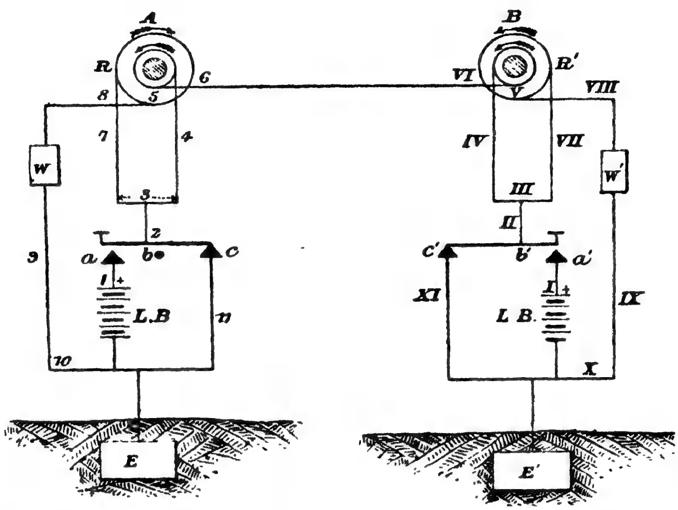
the home key is not, the relay responds because the equating current is absent in the coil r_2. If the home key be depressed, the depression of the distant key causes the main batteries to oppose each other, in which case the signal at each station is given by the action of its own equating battery. By an obvious modification of this plan, the equating circuit might be taken from the main battery B, dispensing with the special battery. In Farmer's arrangement, the continuity of the main circuit is never interrupted, and the resistance of the circuit remains the same, whatever may be the position of the key.

Fig. 1099 is of the principle of W. H. Preece's method. Its characteristic consists in the balance upon the relay of the home station being effected, not by two branch currents of the same battery, but by the entire current in one direction, and a branch of the entire current coming from the other direction. If the relay R of Fig. 1099 is wound with two separate and equal wires, and the branch line c W a disconnected, then any current sent to line by the depression of the key T, or any incoming current from the line L, passing to the earth through the back contact 3 of the key, would have no effect upon the armature of the relay. If the branch c W a be connected, having a resistance equal to that of the line L beyond the point c, and the key T be depressed, the entire current of the battery B would pass through the left-hand coil of the relay, while only one-half of it would pass from the point c to line through the opposing coil, the remainder going to earth by way of c W a. On the contrary an incoming current would also divide at c in the inverse proportion of the resistance c V a and c W a, and the portion passing by way of V would nearly counteract the effect of the undivided current in the other coil. The problem is to weaken as much as possible, the effect of the undivided current in the left-hand coil of the relay at the sending station, together with that of the arriving current in the same coil, which tends to prevent the relay from giving signals by counteracting the effect of the other coil. In practice this result is effected by the use of a Siemens polarized relay, the wire a W c being connected at a point c, between the two coils, which are so wound as to oppose each other, when a current is sent through them consecutively in the ordinary manner. With this arrangement, it is only necessary to remove the adjustable pole-piece of the left-hand coil, to a greater distance from the armature than the right-hand one to effect a balance, so that the relay will respond to incoming currents, but will not be affected by outgoing currents.

Fig. 1100 is a complete plan of the arrangement of Frischen's system at both stations, distinguished by the letters A and B. The main batteries L B at each station are placed with their positive poles to the line, and the negative poles to the earth. R and R[1] are the receiving relays, each wound with two separate coils. The rheostat, W or W[1], in the artificial line at each station, must be so adjusted as to make its resistance exactly equal to that of the line A B, added to that of one wire of the relay at the distant station. If the key at station A is depressed, the current from the main battery L B will divide at the point 3, one portion going by way of 4 and 6 to the line, passing through one coil of the relay, thence from the line through one coil of the relay at the

distant station B, by way VI. and IV. thence by III. and II. to the key lever at b', back contact c' and wire XI., to the earth, the other portion going from 3, in an opposite direction, through the home relay by way of 7, 8, rheostat W, and wires 9, 10 to the earth. These two branches of the current will be equal to each other, and will produce no effect upon the relay at A for that reason. The relay at B, on the other hand, will be affected by the current coming from A, and will respond to the movement of the key at the latter station.

1100.



If now the key at B be also depressed, one half of the battery current tends to go to the line, but as it meets the current from A of opposing polarity, the current in the main line is neutralized or becomes nil. The current in the artificial line at each station being no longer opposed by the line current, will operate the respective relays, and the signals given will correspond to the length of time the key is depressed at the opposite station. Thus each station receives its signal through the action of the distant battery only.

A third position occurs when one of the sending keys, for instance, at B, is in the act of changing from the rear contact c' to its front contact a', in which case the current from A is interrupted at b', and is, therefore, forced to pass through the second coil of the relay, but this time in the same direction, and thence through the rheostat W' to the earth. The current arriving at B is weakened one-half in consequence of the additional resistance encountered at W', but this is compensated for by its passing through both coils of the relay at B, in the same direction, and its total effect upon the relay is not lessened. The difficulty in this connection arises from the fact that when the current at the receiving station is thus momentarily made to traverse both coils of the relay, together with the rheostat, it necessarily causes an unequal division of the current between the two opposing relay coils at the sending stations, as the resistance of the main line becomes about double that of the artificial line, and thus the sender's relay is affected. As this occurs always either at the beginning or the end of a signal, no actual inconvenience is experienced, except possibly when the transmission is unusually rapid. A peculiarity of this, in common with many other methods of simultaneous double transmission in opposite directions, consists in the fact that it may be operated with equal facility, when the main batteries are arranged with agreeing instead of opposing poles.

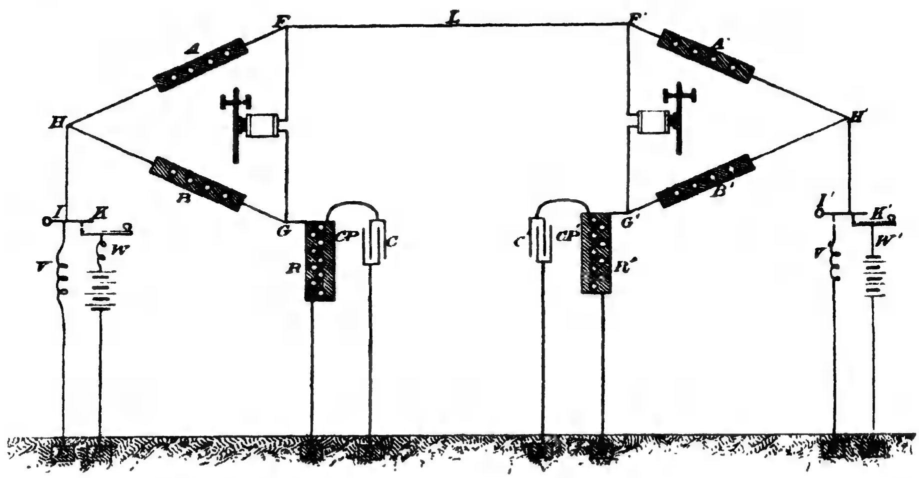
Fig. 1101 is of Stearn's bridge duplex. H, A, B represent the apparatus at either end. In this diagram the line L constitutes one side of the balance, the resistance coil or rheostat R, the opposite side, while the other two sides are formed by two branch circuits A and B. The receiving instrument is placed in the bridge between F and G. The two branch circuits unite at H, and are connected by a wire to the lever I of key K. When the knob of the key is depressed, a current is sent along the wire to H and there branches, a portion passing through resistance coils A to line L, and a portion through resistance coils B and R to the earth.

If the resistance of the branch A bears the same proportion to that of L, as the resistance of B bears to R, then no currents will pass through the relay. When a current from the distant station is sent to line, a portion of it passes through the receiving instrument in the bridge, for, at the point F it finds two paths to pursue, one through the resistance A to the lever l, and small resistance v or w and battery to the earth, and the other through the relay and coils B and R to earth.

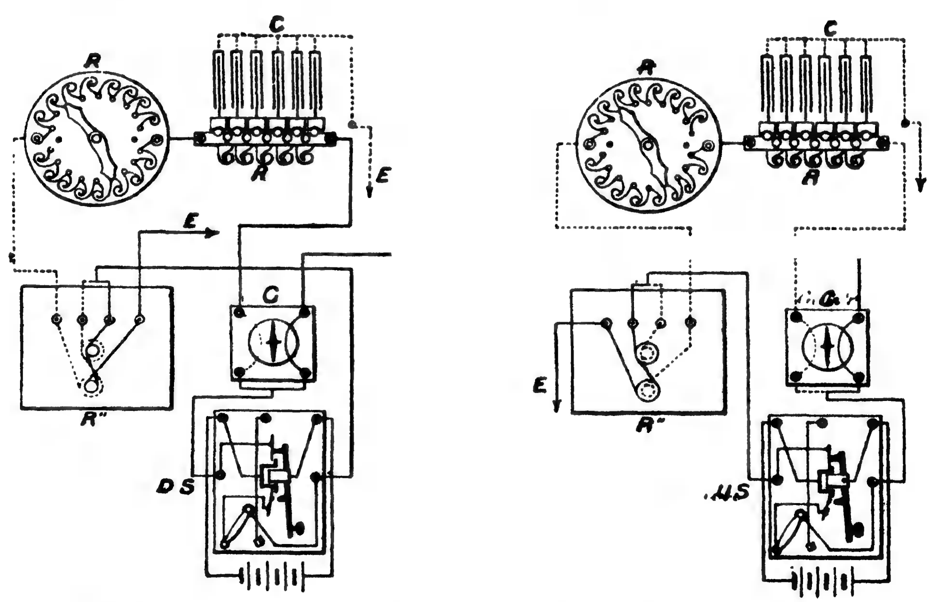
The key K is so arranged that the line is always connected to the earth, either through the back contact direct, or through the front contact and battery: v and w are small resistances, placed in the circuits to prevent the battery being put even momentarily on short circuit, and also for the purpose of maintaining a uniform resistance in the circuit when the line is connected to earth direct, or through the battery. C is a condenser, for compensating the static charge from the line, and is attached by a wire to a brass plate C P, on the rheostat R, which is provided with plugs for connecting it with the resistance coil plates, by which the condenser charge can be sent through any portion of the resistance coils as desired. The method suggested by Frischen, in 1863, in which

he proposed to employ differential polarized receiving instruments, and arrange the key so as to send reversals, has been adapted to Stearns's apparatus in England. Fig. 1102 is the arrangement of the apparatus. The key is provided with a switch, so that the battery may be disconnected when not required for working. A differential galvanometer G is employed for convenience in balancing the resistances with accuracy. The rheostat coils R are arranged in a circle, and contact

1101.



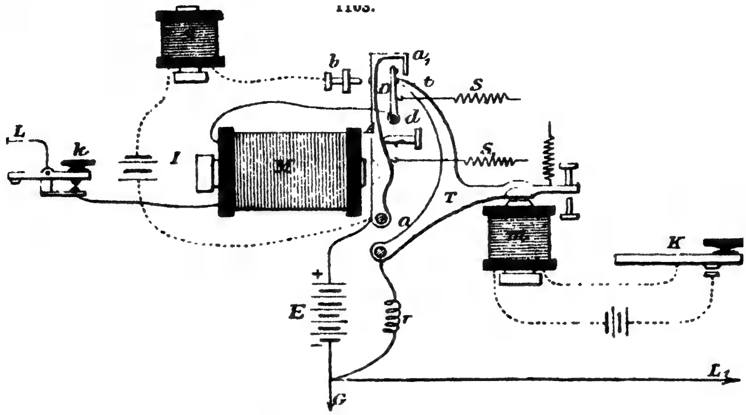
is made by means of two arms resembling the hands of a watch, one of which is connected to the higher and the other to the lower resistances. A series of retardation coils connect R with the condenser C, so that its return discharge may be graduated to correspond with that from the line. R" is a Siemens polarized relay with differential helices; L line, E earth, U S the up station, D S the down station.



In Smith's electro-mechanical method, Fig. 1103, M is the receiving relay, which operates the sounder S in the usual manner by means of the local battery I. The armature lever A of the relay turns on an axle at a, and plays between the front and back contact stops b and c. D is a contact lever having its fulcrum at d. When the transmitter T is in its position of rest, its projecting arm t is in such a position that the arm D is drawn against it, by the tension of the adjustable spiral spring s, and is, therefore, in electrical contact; but when the armature of the transmitter is depressed, the arm t is withdrawn, and the lever D falls back, by the tension of its spring s, against the projecting stop a_1 of the relay armature A. The connections are arranged as follows;—One pole of the main battery E is connected to the fulcrum a of the relay armature A, and the other pole

to earth at G. The fulcrum of the transmitter T is also connected to earth, a spark coil r being inserted, equal in resistance to the battery in the usual manner. The line L goes first to the helices of the relay M, and thence to the fulcrum d of the contact lever D. The transmitter T may be worked directly by hand in the same manner as an ordinary key, but it is preferable to arrange it in the ordinary way with a local magnet m and key K.

1103.



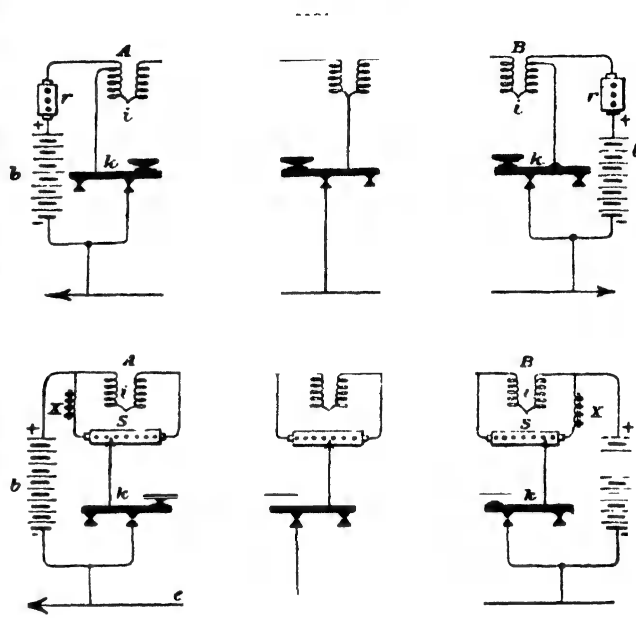
The diagram represents the normal position of the apparatus when not in use. The armature spring s_1 is adjusted to correspond to the incoming currents. When the home station has its key K open, the relay and sounder respond to the writing of the distant operator. The currents entering at L pass through the relay M, and thence find their way to the earth by way of the contact lever D, transmitter T, and spark coil r. The upper spring s is so adjusted that when acting in conjunction with the spring s_1 their combined pull will hold the armature lever A in its back stop c, with sufficient force to withstand the attraction produced in the relay magnet M by the action of the main battery E, either at the home or the distant station alone, but the combined effect of the two batteries, when both of them are in circuit at the same time, will be sufficient to overcome the combined tension of the springs without difficulty. When the armature of the transmitter T at the home station is depressed, the arm t is drawn back; and the spring s pulls the contact lever D against the stop a_1 of the armature lever A, which connects the main battery E to the line through the home relay M, but at the same time the combined tension of the two springs s and s_1 is exerted to prevent the armature from responding. If the distant key is depressed, and the battery of the distant station also placed in circuit, the tension of both springs is overcome, the armature A responds to the increased attraction of the magnet M, and closes its local circuit at b, thus recording the signal from the distant station. It is necessary that the main batteries should be placed with unlike poles towards each other, as in the ordinary closed circuit system.

Fig. 1104 is of Winter's method. A and B represent the two terminal stations; I is the line between them. At each station i is the receiving instrument, k key, b battery. c the earth connection, and r a resistance coil. Suppose one-tenth of the wire of the instrument is between k and r and nine-tenths between k and I; let the resistance r be nine-tenths that of the line, and let the insulation of the line be supposed perfect. If, now, the key at A is depressed, the battery b is on short circuit through the resistance and one-tenth of the instrument. The current from the battery at B flows through the whole of the instrument at B, the whole of the line wire and nine-tenths of the instrument at A. Its action upon the instrument at A is antagonistic to that of the battery acting locally at that station, and it has to go through about nine times the resistance; it has only about one-ninth of the strength of the current of the battery on short circuit at A, but as it has nine times as many convolutions of the instrument wire to pass through, the actions are just balanced, and the instrument at A is unaffected. At B, however, it is evident that the battery acts on the whole of the coil of the instrument, and produces a signal accordingly, which is only slightly weakened by the insertion of the resistance r. When B communicates with A, matters are simply reversed. When both keys are depressed at once, the battery at each station acts locally, and the action on each instrument is only about one-tenth less than the action of the whole of the battery when, after traversing the line, it acts upon the whole of the coil of the instrument as in single sending.

With another but less effective method by the same inventor, Fig. 1105, the key, instead of being connected to a point in the wire in the interior of the instrument coil, is joined to a point in a resistance s acting as a shunt on the receiving instrument, much nearer to the battery end of the shunt than the line end. A suitable proportion between the resistance s and the instrument coils is 4 or 5 to 1. The point where the key is connected may, if required, be made adjustable by means of a sliding contact. Both the above arrangements can be applied to intermediate instruments very simply, by making the point where the key is connected nearer to the middle of the instrument coil in the first arrangement, and of the shunt in the second method. The intermediate stations can then communicate with each other, or the terminal stations, in duplex, and without batteries.

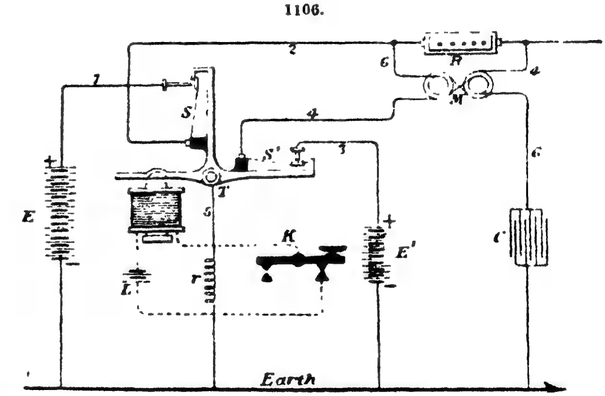
The effect of the static induction of the line in the opposed battery system is as follows;— When both keys are in their normal position, the potential of the whole line is raised or lowered by the opposing batteries above or below that of the earth, and the line will in consequence hold a

charge which will depend for its quantity upon the inductive capacity of the line. When either of the keys is depressed, the potential of the circuit at that point will be the same as that of the earth, and half the charge of the line will flow out through the line coil of the instrument. In the second of the two systems, Fig. 1105, the effect of the charge and discharge will be lessened by part being carried off by the shunt. At each depression of the key, a strong instantaneous current is flowing in one direction through the line coils of the instrument, and when the key is raised there is another instantaneous current flowing in the opposite direction through the whole coil. The effects of the discharge, when not compensated, are, on the whole, much less marked in this than in the open circuit system. Winter's method of effecting the compensation for the inductive discharge is by winding the shunt on the battery side of the key upon an iron core, as at X, Fig. 1105.



The transmitter T, Fig. 1106, of G. Smith's electro-mechanical method, is worked either directly by the finger of the operator, or preferably, by a magnet, local battery and finger key K, as in the Stearn's duplex. It is so arranged that the two batteries E and E¹ are both placed in circuit simultaneously whenever the key is depressed. The circuit of battery E when closed, passes through the wire 1, spring S of the transmitter T, wire 2, and rheostat R to the junction of wire 4 and the line, where it meets the opposing current from battery E¹, which comes through wires 3 and 4, including one wire of differential relay M. The current of the principal battery E is materially weakened by the resistance of the rheostat R, so that a much smaller battery E¹ is sufficient to oppose its tendency to find its way back to the earth through the wire 4 and relay M. It therefore goes over the line to the distant station, and operates the instrument at that point. Thus the first condition of duplex working is provided for, as the two batteries E and E¹ neutralize in the wires 3 and 4 and relay M. The currents received from the distant station, over the line, divide at the junction of the wire 4, one portion going to the earth through the rheostat R and wire 2, and the other portion through the wire 4 and relay M, recording the signal. So far as the strength of the outgoing current is concerned, it is quite immaterial what the resistance of the relay M is, and this may therefore be made of whatever resistance will produce the most favourable effect with the incoming currents.

1106.

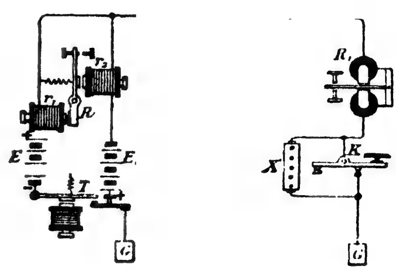


An ordinary relay might be used with this duplex, but in practice it has been found preferable to substitute a differentially wound relay. The extra circuit of this forms a part of the wire 6, which is attached to the battery 2, and to one side of a condenser C, the other side of which is connected to earth. By this contrivance the return current or static charge is effectually compensated. When the circuit of the battery is closed, the condenser C takes a charge. When the battery is removed from the circuit, the line and the condenser discharge themselves simultaneously, but the two charges pass off in opposite directions through the two wires of the differential relay, and their effect upon its cores is nil. The resistance of the spark coil r should be made equal to that of the joint resistance of the batteries E and E¹. The balance of the whole system is obtained by varying the rheostat R.

Instead of a transmitter with the continuity preserving springs S S, an arrangement might be used which would short circuit both batteries when the key is up, by a connection which would be interrupted when the latter is depressed, so as to allow the current to flow to line.

In a method of simultaneous transmission, invented by T. A. Edison in 1873, Fig. 1107, the signals are transmitted in one direction by reversing the polarity of a constant current and in the opposite direction by increasing and decreasing the strength of the same current. The relay R at station A consists of two soft iron electro-magnets r_1 and r_2, which act upon the same armature lever, closing the local circuit of the sounder or other receiving instrument in the usual manner. The transmitter T is operated by a key and local battery as in Stearn's method, and is so arranged that when the key is in a position of rest the negative current from the battery E_1 passes to line through the electro-magnet r_2 of the home relay R; but if the key is depressed, the lever T of the transmitter makes contact between the battery E and earth G, and at almost the same instant interrupts the previously existing contact between E_1 and the earth. There is at all times either a positive current going to line through r_1, or a negative current through r_2. At station B the currents pass through a polarized receiving instrument R_1, and thence through a rheostat X to the earth. The tension of the spring of relay R is adjusted, so that the current going to line is not sufficient to overcome it, except when the rheostat X is cut out by depressing the key K at station B. Consequently A sends to B by reversing the polarity of the current, without changing its strength, while B sends to A by changing the strength of the current irrespective of its polarity. The polarized relay can be placed at a number of stations on the line, and each will be able to receive the signals from the stations transmitting the positive and negative currents. A neutral or Morse relay may also be placed at a number of stations, if devices are employed to prevent the mutilation of the signals by change in the polarity of its iron core.

1107.



The principle embodied in this invention has been successfully employed in quadruple transmission, by modifications in the arrangement of the apparatus.

Vianisi has invented a system for duplex working, based on the Poggendorff bridge. Both systems agree in the arrangement of the batteries so far, that the balance is obtained in the circuit containing the one battery, and differ in that Vianisi chooses as line, the circuit containing the second battery. Calculation proves that both electrical systems suffer from the disadvantage that the portion of the current entering the line is comparatively weak. One of the nine combinations of the system designed by Vianisi differs from the others in effecting the balance in the receiver of the sending station, by means of a current coming from the receiving station, consequently each station requires but one battery.

When neither key is depressed, both batteries are closed, but since similar poles are connected to the line, the currents, being equal and opposite, do not produce any effect. When station I is sending, its own battery is short-circuited through I's receiver. When both I and II send, each battery acts upon its own receiver, the currents passing through the line, neutralizing one another.

The basis of the system is explained as follows. Let Fig. 1108, the opposite poles of two batteries, B_1 and B_2, whose electro-motive forces are equal to E_1 E_2, be connected by wires, and let a suitable receiver be connected at two points, a and B. If the strength of the currents in the three branches be indicated by J_1, J_2, J_3, and the resistances by W_1, W_2, and W_3, according to Kirchoff's laws there will be obtained

$$J_1 - J_2 - J_3 = 0.$$
$$E_1 = J_1 W_1 + J_3 W_3.$$
$$E_2 = J_2 W_2 - J_3 W_3.$$

From these equations the following values may be deduced ;—

$$J_3 = J_1 - J_2.$$

$$W_2$$

$$J_2 = \frac{E_2 + J_3 W_3}{W_2} = \frac{E_1 - J_3 (W_1 + W_3)}{W_1}.$$

Obviously, $J_3 = 0$, if $E_1 W_2 - E_2 W_1 = 0$.

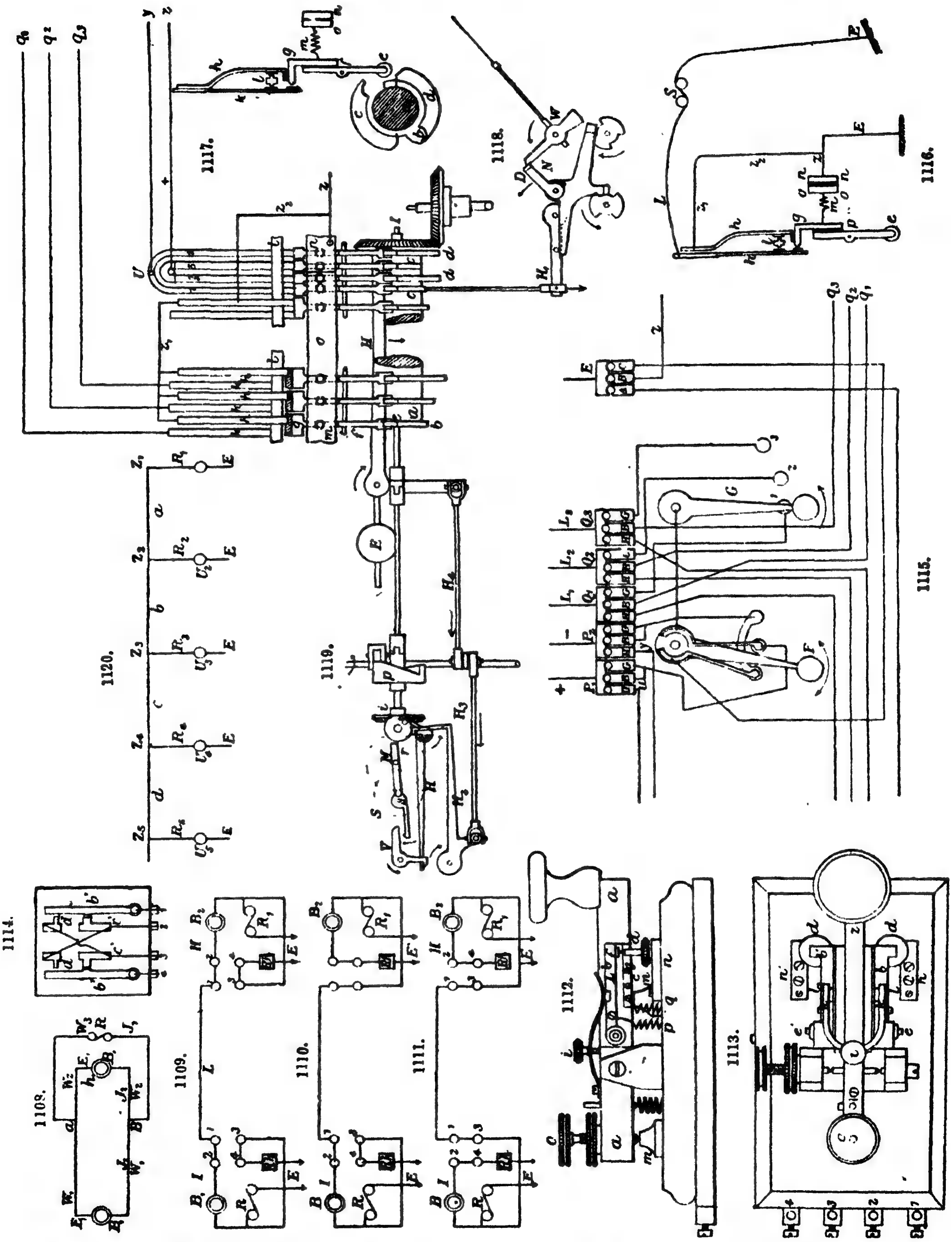
The equations are of use when one station is sending but not receiving. Figs. 1109 to 1111 are modifications of the method.

The key, Fig. 1112, when depressed, breaks two circuits and establishes two new ones without interrupting the line. Two auxiliary levers b b', Fig. 1113, are added to the ordinary key lever. These are insulated from the main lever by ebonite plates, which are movable around the axes e and e'. At rest, the auxiliary levers, by the forked spring k and k_1, which may be tightened at will by means of a screw i, are pressed upon the insulated contact pieces c and c'. The arms k k_1 of the spring are not in metallic contact with the auxiliary levers, and they press against the plates of ebonite l l. The metal plates n and n', are screwed firmly to the bottom of the apparatus below the auxiliary levers, and they have attached to them movable contact pins. If the key be pressed down, the auxiliary levers b and b' come into contact with the studs d and d'; and if the pressure on the key be continued, they are raised finally off the points of contact c and c'. If the key be allowed to rise again, then b and b' come into contact with c and c', and only b and b' break contact with d and d'.

The connections of the binding screws 1 to 4 become clear from Fig. 1114. At rest, the terminals

1 and 2 are in metallic connection by b and c; also the terminals 3 and 4 by b' and c'. When the key is depressed, a current entering at 1 flows to 3 by b, d, and c', and a current entering at 2 flows to 4 through c, d', and b'. During the motion of the key no interruption occurs, except a short circuiting of the battery, as the connections b, d, and b' d' are established before the contacts between b, c, and b' c' are removed.

The adjustment of the apparatus is simple. The studs d and d' should be equal in height.



When the key is in use, care must be taken not to injure the thin spiral wires p and q, Fig. 1112, which establish the connection between the auxiliary levers and contact pieces with the binding screws. Fig. 1114 is a plan of the key connections.

In the plans of the circuits, Figs. 1109 to 1111, the key is indicated by the four terminals

connected in pairs. The rheostats *Rh* allow an insertion of from 1 to 4000 units. The receivers R, R_1 are Morse ink writers with movable electro-magnet and double springs. The battery consists of a modification of Meidinger elements.

When both keys are at rest.—At each station 1 and 2, 3 and 4 are connected: both batteries B have copper to line, with zinc, through receiver and resistance, to earth E. As the two opposed currents are of equal strength, the line, completely insulated, is free from a current.

Key at station II pressed down; at station I at rest. At II the points 1 and 3, 2 and 4 are connected; at 1, as before, 1 with 2, and 3 with 4. The positive current of battery B goes through line L to II, flows through two parallel branches, through the receiver R_1, the resistance, and returns through earth to I through the parallel branches Rh_1 and Rh_2. But the receiver of the sending station II is influenced at the same time by its own battery, the positive current from which enters from below through *Rh* into the Morse R_1; thus a balance of the two opposite currents may be effected in R_1. The plan, Fig. 1109, appears to be identical with Fig. 1110. W_1 of the equation, is represented by the combined resistance of line L of battery B, of the branches R and *Rh* and of the earth; W_2 by B_2 and resistance *Rh*; and W_3 corresponds with the resistance of the writing instrument R_1 of the sending station. If $W_1 = W_2$, E_1 being henceforward taken as equal to E_2, then, according to the equations, the receiver R_1 would remain entirely free from a current. This is not always the case; sometimes a weak current passes through the Morse instrument of the single sending station, and this current is not sufficiently powerful to attract the armature.

Both keys depressed.—The points 1 and 3, 2 and 4 are connected at both stations. The positive current passes in both stations through rheostat and receiver to the zinc pole. The zinc pole of both batteries is connected to line; therefore the currents neutralize each other in the line.

As a practical example as to the difference existing between the single and duplex signals, let there be given the resistance of the line equal to 1200 units, that of the receiver as equal to 400 units, and let the resistance in each rheostat be 1600 units, equal to line + receiver inserted. Resistance of the earth = 0. At each station are placed 18 Meidinger cells, of which the combined electro-motive force = 18, and total resistance = 108 units.

According to the equations,

$$W_1 = 1628;\ W_2 = 1708;\ W_3 = 400.$$
$$J_3 = 0\cdot00035;\ J_1 = 0\cdot0109;\ J_2 = 0\cdot0106.$$

As the rheostat *Rh* is arranged as a shunt for the receiver, only $\frac{4}{5}$ths of the current pass through the receiver, and $\frac{1}{5}$th through the rheostat, the ratio of the resistances of both parallel being as 1 : 4; from this

$$\tfrac{4}{5}\,J_1 = \tfrac{4}{5} \times 0\cdot0109 = 0\cdot0087.$$

Let the magnetic moment of the receiving magnet be equal to the strength of current, multiplied by the square root of the magnet's resistance, then we have

$$M_1 = \tfrac{4}{5}\,J_1 \sqrt{W_3} = 0\cdot0087 \times 20 = 0\cdot1740.$$

The receiver of the sending station receives a magnetic moment, 20 J_3 or 0·00700, which is incapable of producing any effect.

In case 3, for each station, $J = 0\cdot0085$; $M_3 = 0\cdot0085 \sqrt{400} = 0\cdot1700$.

The difference of the magnetic moments in cases 2 and 3 is $D = 0\cdot004$, consequently the single and duplex signals are almost of equal strength.

In Vianisi's first arrangement, the terminals 3 and 4 were insulated when the key was at rest, therefore the current acted with full force on the receiver at I, since the shunt R did not exist. Consequently W_1 could be made equal to W_2, therefore the current J_3 and magnetic moment in $R_1 = 0$.

In pursuance of the calculation with the numerical values given above, in case 2, the magnetic moment of the receiver R_1, $M_1 = 0\cdot2100$.

In case 3, as above, $M_3 = 0\cdot1700$, and thus $D_1 = 0\cdot04$; that is greater than in the preceding instance.

Receivers of too great a sensitiveness will not work so accurately under these circumstances.

The difference between the simple and duplex signals in the first example can be further reduced by inserting a resistance coil of 40 units at each station between the terminal 4 and the line; then in case 2;—

$$J_3 = 0;\ J_1 = J_2 = 0\cdot0105;\ M_1 = \tfrac{4}{5}\,J_1 = \sqrt{W_3} = 0\cdot1680.$$

For case 3, as before stated, $M_3 = 0\cdot1700$, $D_2 = 0\cdot002$.

A small galvanometer or detector is inserted between the receiver and the earth. The resistance of it, 2·5 units, has to be considered in the numerical examples.

The receiver of the sending station shows inertia. For trial, I is arranged as in Fig. 1108. The receiver was at first a Hipp's relay magnet; then a Siemens polarized relay; succeeded by a Hughes instrument. To make R work, the following alterations of W_1 were necessary; W_1 and W_2 were originally rheostats of 500 units each. 1st. $W_1 = 320$ units. 2nd. $W_1 = 360$ units. 3rd. $W_1 = 460$ units. In the last case, the Hughes magnet was adjusted to extreme sensitiveness.

This duplex method is applicable to the Hughes instrument, Figs. 1115 to 1119.

Vianisi's automatic repeater is a relay intended for transmission, whose contact lever interrupts two currents, and establishes two new ones. This relay is inserted in the local circuit of the sending Hughes instrument. The mechanical locking of the printing axis applied to the new Hughes telegraph affords a means for adapting Vianisi's method. For this purpose, a system of auxiliary levers is applied to the contact lever of the sending Hughes, Figs. 1116 to 1119. The

movable parts b, b' must work easily. The plan of insertion does not differ from that in Figs. 1116 and 1119.

A numerical example of the bridge method, modified and applied to the Hughes instrument, will illustrate the principle.

Resistance of line, 80; of one Hughes, 20; of one element, 0·12, all the resistances being expressed in rheostat units, each equal to 50 Siemens units. The strength of current required to work a Hughes is 0·73, and 80 to 96 elements are requisite for single working.

Taking 100 elements. In case 2;—$J_3 = 0{\cdot}0205$; $J_1 = 0{\cdot}917$; $J_2 = 0{\cdot}8965$.

As in the first example, the rheostat forms a shunt to the Hughes magnet, $\frac{5}{6}$ J will flow through the coils, or $\frac{5}{6} \times 0{\cdot}917$; that is, 0·764. But when the armature of the receiving Hughes strikes the locking lever, the coils are short-circuited and the values are altered; and

$$J_3 = 0{\cdot}139;\ J_1 = 1{\cdot}056;\ J_2 = 0{\cdot}917.$$

The current J_3, which flows through the receiving Hughes of the sending station, strengthens the induced magnetism of the cores, since it flows in a direction opposite to that which produces the signals at II. If, now, station I begins to send, a sudden reversal takes place in the magnet at station II.

Fig. 1115 shows a Hughes connected with two batteries and two rheostats. Between P and P' a key is inserted, whose depression suddenly breaks the circuit of the battery P. Having first made $W_1 = W_2$, W_1 is gradually diminished, which has the effect of strengthening the cores in R, and the sudden depression of the key causes the magnet to be acted on by P' only. With the magnet adjusted, the locking of the printing axis is easily effected.

In case 3, the current acting on each Hughes is

$$J = 0{\cdot}757,$$

and the difference of currents in cases No. 2 and No. 3 = 0·007. J_3 could be made = 0, by the insertion of a resistance coil. There are 333 elements required to obtain a current of J = 0·73 in the previous example; but the bridge method is applicable to both old and modern Hughes instruments without auxiliary mechanism. Fig. 1120 is self-explanatory of the means of connecting intermediate stations.

M. Sieur's duplex system is distinct in principle. It is based on the use of a distributor or automatic current reverser, which divides up the time of sending into a series of small and equal intervals, during which a succession of alternating positive and negative currents, each current occupying an interval, are sent into the line. These currents are received separately on two polarized relays, one relay responding to the positive and the other to the negative currents. The system admits of sending two messages in the same direction simultaneously, or two messages in contrary directions. The distributor is the same in either case, and consists of a cam D, Fig. 1121, connected to earth and turning by clockwork between two steel springs C Z, which it raises alternately as it rotates. If the cam revolves at a speed of twenty turns a second, it will raise during one-fortieth of a second the spring C, and being in contact with earth, it will put the positive pole of the battery to earth during that time, whilst the negative pole, through the spring Z, is in connection with the stud P of the key B. Passing on from the spring C, which returns to its stud A, the cam raises the spring Z, breaking contact with B. The negative pole of the battery is thus put to earth while the positive pole is connected to the stud P of the key A. During each revolution of the cam, the two poles of the battery are thus alternately drawn upon, but the intermittent currents from each are led to separate signalling keys A and B. If the key A alone is manipulated, a positive intermittent current is sent into the line, the interruptions succeeding one another at intervals of one-fortieth of a second. If the key B be worked a series of similar negative currents enter the line.

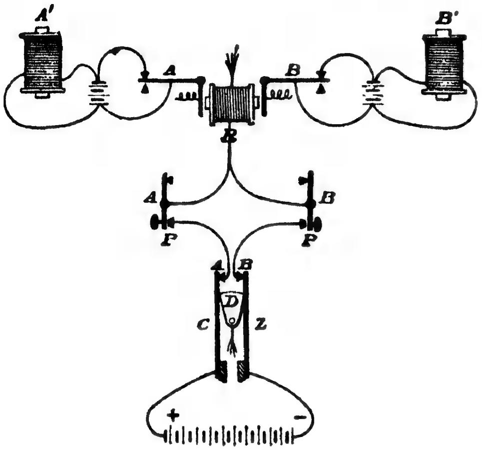
The receiver is a polarized relay with two armatures, the armature A only answering to positive currents, and the armature B to negative currents. Two polarized relays with a single armature will serve the same purpose. The armature B, which can only act under the influence of the negative current, remains passive on its upper contact, short-circuiting the local battery which actuates the recorder B; but the armature A is attracted by the positive currents into contact with its lower stop; breaking the short circuit and enabling the local battery to signal on the recorder A. The armature A is only attracted for one-fortieth of a second at intervals of one-fortieth of a second, but the recorder A can be so adjusted as to bridge over the interruptions, and give entire signals, while the key A is depressed, just as if the current were continuous. In the same way, when the key B is manipulated, the recorder A is passive, while the negative intermittent current from B attracts the armature B, breaks the short circuit, and allows the recorder B to signal. If both keys operate together in sending two different messages simultaneously, both armatures will simultaneously respond, each to its respective key, and both recorders, each to its respective armature.

In the arrangement considered, the armatures in vibration are caused to actuate the recording instruments, but by another method, Fig. 1122, they can be made to signal when at rest. Instead of connecting the springs of the distributor to the studs P of the keys, they are connected in this case to the studs r on which the lever of the key bears when at rest. A series of intermittent currents are in this way continually flowing into the line, positive from the key A, negative from the key B. These currents cause the corresponding armatures of the relay to vibrate continually. The local recording circuits are so joined up to the armatures, as to be closed when the armatures are at rest on the upper stops, and open when the armatures vibrate, for the rapidly intermitting currents cause the armatures to vibrate freely midway between both upper and lower stops. On depressing the key A, contact is broken at r, the positive current ceases to flow and the armature to vibrate. It returns to its rest stop, completes the local circuit, and causes the recorder A to signal. Similarly

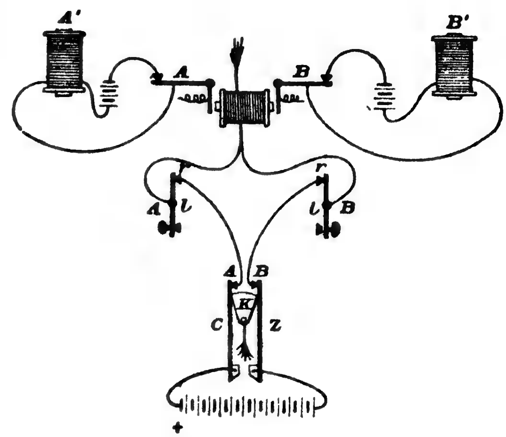
the key B causes the recorder B to signal; and when both keys act at once, both recorders respond together, each to its proper key.

When sending two messages in contrary directions, each station must be able to send a message without interfering with its own receiving instrument. Let the two stations be called respectively S and S′. Only the station S is provided with a distributor, and it is of the form shown in Fig. 1122,

1121.



1122.

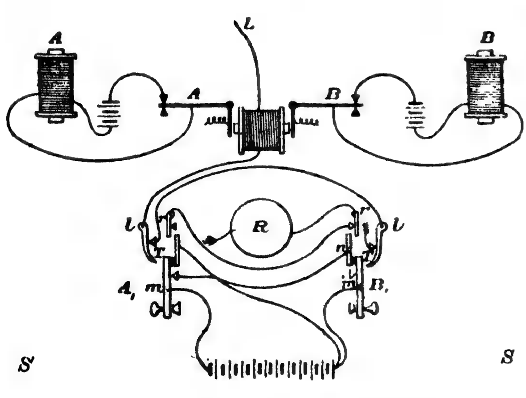


that is, the wires from the middle of the keys l unite; but before entering the line they are connected through the receiving relay. Fig. 1123 is the arrangement of apparatus at station S′. The relay at both stations is so joined up, that the armatures A vibrate under the negative currents from S, and the armatures B under the positive currents. The levers m, n of the signalling keys are each made in two metal parts insulated from one another. In the position of rest, the distributor of the station S sends into the line a series of alternating currents, which traverse the relay at S, and also that at S′, where they flow to earth by the levers l and the contacts T of the keys A_1 and B_1. At both stations the armature A and B of the relays oscillate, but have no action on their recorders.

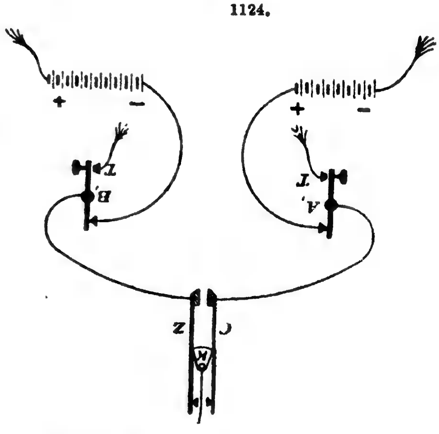
When the key A_1 at station S, Fig. 1123, is alone depressed, the armatures A at both stations stop vibrating, and the corresponding recorders signal. Similarly when B_1 is depressed the corresponding recorders at both stations also signal. Hence the sending of station S operates both relays and recorders.

When the key A_1 of station S, Fig. 1123, is alone depressed, the part m of the bar makes contact with the lever l and raises it, while the part n raises the lever r. The negative current from the battery reaching the part n, passes by the lever r or the key A_1, the contact piece, and the lever r

1123.



1124.



of the key B_1, and goes to earth through the rheostat R, whilst the positive current passing by the part m and the lever l of the key A_1 enters the line. These positive currents from S′ strengthen the negative currents from S; but the rheostat R in circuit, is adjusted so as to reduce the intensity of the current so produced, to the intensity of a single negative current. The negative currents from S, therefore, act as if the key A_1 of station S′ were at rest, and the armatures B at both stations continue to oscillate. Conversely the positive currents from S are neutralized by the positive current sent into the line from S′; and consequently the armatures A at both stations

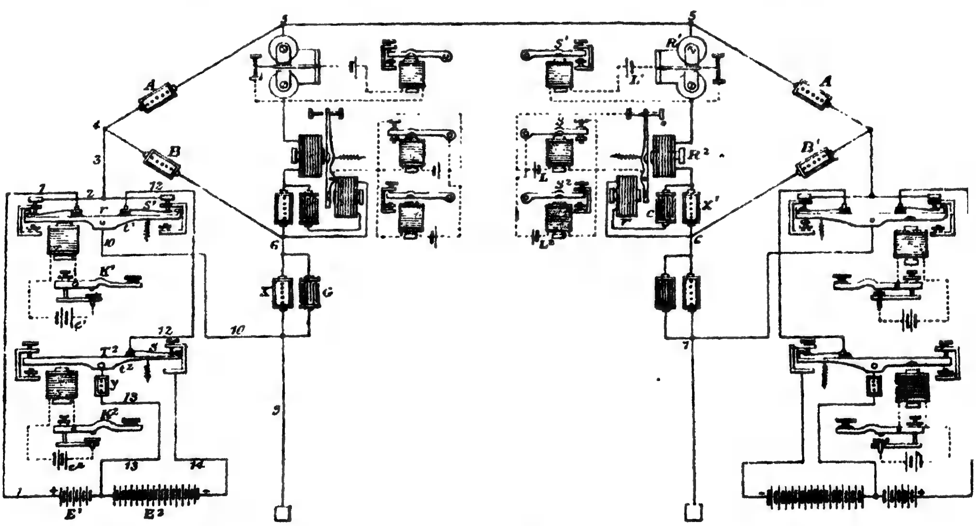
cease to oscillate, thus actuating the recorders. If the key B_1 of the station S′ transmits alone, the part m of the bar raises the lever l, while the part n raises the lever r. The positive current, passing by m of the key A_1 and its resting stud T, to n of the key B_1, and the lever r, goes to earth by the rheostat R, whilst the negative current, passing by m and the lever l of B_1, the contact T and lever l of A_1, enters the line, where it does not affect the positive currents from S, but neutralizes the negative currents. At both stations, therefore, the armatures A continue to oscillate, but the armatures B are stopped. When both keys of station S′ act together, the positive pole of the battery is connected to the line by the part m and lever l of the key A_1. But the negative current, passing by the part m and lever l of the key B_1 is insulated at the contact T of the key A_1; and the same pole passing by the part n and lever r of the key A_1 is insulated also at the contact piece of the key B_1. There is consequently a breach in the line circuit, and the armatures of both the relays act, and both the recorders signal.

When the key A_1 or station S transmits at the same time as the key B_1 of station S′, the depression of the former suppresses the emission of positive currents from S, while the depression of the latter sends over the line a negative current which neutralizes the negative currents issuing from S; consequently there is no current on the line, both the armatures stop, and the recorders signal. The same effect takes place, but by an inverse process, when the key B_1 of station S is depressed at the same time as the key A_1 of station S.

When the key A_1 of station S transmits at the same time as the key A_1 of station S′ or the key B_1 of S at the same time as the key B_1 of S′, because the positive current sent out by S′ does not affect the negative one from S, the stoppage of the positive current from S affects the armatures of the relays A at both stations, the same as if the key A_1 at station S had not been depressed. Similarly the effect of depressing the key B_1 at station S′ while the key at station S is depressed is the same as if the latter alone was depressed, both B relays are operated.

Fig. 1124 is of a method of simultaneous transmission by this system, in which separate batteries and ordinary contact keys are employed.

Quadruplex Telegraphy.—Fig. 1125 is of Edison's quadruplex apparatus upon the bridge plan. r is a double current transmitter or pole changer, operated by an electro-magnet, local battery c^1, and finger key K^1. The office of the transmitter r is simply to interchange the poles of the main battery E^1, with respect to the line and earth wires, whenever the key K^1 is depressed; or, in other words, to reverse the polarity of the current upon the line by reversing the poles of the battery E^1. By the use of properly arranged spring contacts, s^1 s^2, this is done without at any time interrupting



the circuit. Thus the movements of the transmitter r cannot alter the strength of the current sent out to line, but only its polarity or direction. The second transmitter T^2 is operated by a local circuit, and key K^2 in the same manner. It is connected with the battery wire 12 of the transmitter r, so that when the key K^2 is depressed the battery E^1 is enlarged by the addition of a second battery E^2 of two to three times the number of cells, by means of which it is enabled to send a current to the line of three or four times the original strength, but the polarity of the current with respect to the line still remains as before under control of the first transmitter r.

At the other end of the line are the two receiving instruments, R^1 and R^2. R^1 is a polarized relay with a permanently magnetic armature, which is deflected in one direction by positive, and in the other by negative currents, without reference to their strength. This relay consequently responds solely to the movements of key K^1, and operates the sounder S^1 by a local circuit from battery L^1 in the usual manner. Relay R^2 is placed in the same main circuit, and is provided with a neutral or soft iron armature. It responds with equal readiness to currents of either polarity, provided they are strong enough to induce sufficient magnetism in its cores, to overcome the tension of the opposing armature spring. The latter is so adjusted that its retractile force exceeds the magnetic attraction

induced by the current of the battery E^1, but is easily overpowered by that of the current from E^1 and E^2 combined, which is three or four times as great. Therefore the relay R^2 responds only to the movements of K^2 and transmitter T^2.

A difficulty occurs when the polarity of the current upon the line is reversed during the time in which the armature of R^2 is attracted to its poles, for the armature will fall off for an instant, owing to the cessation of all attractive force, when the change of polarity is actually taking place, and this would confuse the signals by false breaks, if the sounder were connected in the ordinary way. By the arrangement shown in the figure the armature of the relay R^2 makes contact on its back stop, and a second local battery L^2 operates the receiving sounder S^2. Thus when relay R^2 attracts its armature, the local circuit of sounder S^2 will be closed by the back contact of local relay S; but if the armature of R^2 falls off, it must reach its back contact, and remain there long enough to complete the circuit through the local relay S and operate it before the sounder S^2 will be affected. But the interval of no magnetism in the relay R^2, at the change of polarity, is too brief to permit its armature to remain on its back contact long enough to affect the local relay S, and through the agency of this ingenious device the signals from K^2 are properly responded to by the movements of sounder S^2.

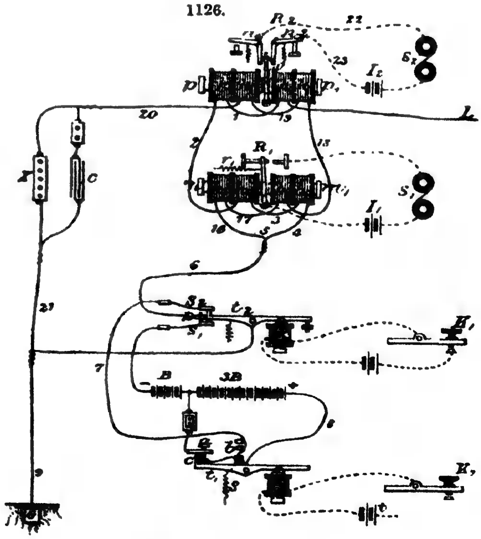
By placing the two receiving instruments R^1 and R^2 in the bridge wire of a Wheatstone balance, and duplicating the entire apparatus at each end of the line, the currents transmitted from either station do not affect the receiving instrument at that station. The duplicate parts which are not lettered operate in precisely the same manner, but in the opposite direction with respect to the line.

In applying this system of quadruplex transmission upon lines of considerable length, it was found that the interval of no magnetism in the receiving relay R^2, which takes place at every reversal in the polarity of the line current, was greatly lengthened by the action of the static discharge from the line, so that the employment of the local relay S was not sufficient to overcome the difficulties. A rheostat or resistance X^1 was therefore placed in the bridge wire with the receiving instruments R^1 and R^2, and shunted with a condenser c of considerable capacity. Between the lower plate of the condenser and the junction of the bridge and earth wire, an additional electro-magnet v was placed, acting upon the armature lever of the relay R^2, and in the same direction. The effect of this arrangement is, that when the current of one polarity ceases, the condenser c immediately discharges through the magnet v, which acts upon the armature lever of relay R^2, and retains it in position for a brief time before the current of the opposite polarity arrives, and thus serves to bridge over the interval of no magnetism between the currents of opposite polarity. The combination of transmitted currents in this method differs materially from any of those used in other inventions. They are as follows;—

When the first key is closed and the second open	+ 1
When the second key is closed and the first open	− 3 or − 4
When both keys are closed..	+ 3 or + 4
When both keys are open	− 1

Another very important practical advantage in the system under consideration, is due to the difference or working margin between the strength of currents required to produce signals upon the polarized relay, and upon the neutral relay respectively, and this may be increased to any extent which circumstances render desirable. Within certain limits the greater this difference the better the practical results, for the reason that the range of adjustment of the neutral relay increases directly in proportion to the margin. The ratio of the respective currents has been gradually increased from 1 to 2, to as high as 1 to 4, with a corresponding improvement in the practical operation of the apparatus.

1126.



Before it became possible to produce a quadruplex apparatus capable of being worked at a commercial rate of speed upon long lines, it was essential that its component parts should have arrived at a certain stage of development. When, in 1872, simultaneous transmission in opposite directions was for the first time rendered practicable upon long lines by the combination therewith of the condenser, the first step was accomplished. It now only remained to invent an equally successful method of simultaneous transmission in the same direction, which was done in 1874.

G. Smith, in 1876, effected several important improvements in quadruplex telegraphs, Fig. 1126. Both receiving relays R_1 and R_2 are provided with differential helices and polarized armatures, and in general the differential method is employed throughout in place of the bridge. The relays R_1 and R_2 may be constructed as shown in the figure, or according to Siemens' pattern. Experience has shown that the latter form gives, on the whole, the most satisfactory results, and it has there-

fore been adopted in all the more recent apparatus. The combination of the outgoing currents differs from that employed in the original quadruplex, and is as follows;—

K_1 open and K_2 open, current traversing line	.. ..	$+$ 4 B
K_1 open and K_2 closed " " "	.. ..	$+$ B
K_1 closed and K_2 open " " "	.. ..	$-$ 4 B
K_1 closed and K_2 closed " " "	.. ..	$-$ B

As in the original quadruplex, key K_1 controls the polarity of the current going to line, but the depression of K_2 decreases the outgoing current, irrespective of its polarity, from 4 B to B, or, in other words, cuts off the battery 3 B altogether.

The action of the relay R_2 is that only requiring detailed explanation. When both keys are at rest the positive current of both batteries + 3 B + B is passing over the line, and the polarized armature is pressed against the contact lever n_1, which yields, thus allowing it to separate from the contact lever n_2, and the circuit of the sounder S is broken. When K_1 is closed, the polarity of the entire battery upon the line is reversed, and the armature passes over to the other side and presses against n_2 in the same manner, so that the sounder S_2 cannot be operated by the stronger currents of either polarity. But the depression of the key K_2 in either case decreases the current, until it is unable to withstand the tension of the springs of the contact levers n_1 n_2, and thus the local circuit through the sounder S_2 is completed, and the latter responds to the movements of key K_2. On circuits exceeding 200 miles the sounder S_2 is preferably operated through a local relay. The combination of the outgoing currents in different positions of the keys is also re-arranged, as—

K_1 open and K_2 open, current traversing line	.. ..	$+$ B
K_1 open and K_2 closed " " "	.. ..	$+$ 4 B
K_1 closed and K_2 open " " "	.. ..	$-$ B
K_1 closed and K_2 closed " " "	.. ..	$-$ 4 B

An example of a totally different system of multiple transmission, is that based upon the principle of the division of a single current into rapidly recurring waves or pulsations, first attempted by Farmer in 1852, and used in Meyer's apparatus.

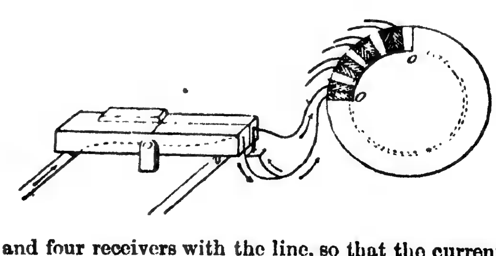
This system is intended to utilize all the currents that in a given time can be made to succeed each other in a wire, so that several operators, each sending twenty to thirty messages an hour, may transmit them upon the same wire.

The number of transmissions that a telegraph line will carry varies with its conducting power. It is generally admitted that, with a speed of twenty-five messages an hour, on a Morse instrument, about five pulsations of the current occur a second. Consequently, n being the sum of the currents which in a second can succeed each other in a conductor, $\frac{n}{5}$ represents the number of receivers which it is possible to establish upon a single wire, or the number of operators that can work at the same time.

The apparatus is usually constructed for four transmissions, and is worked by four operators. At a speed of seventy-five revolutions a minute, presenting four letters at each turn, it records one hundred messages an hour with twenty pulsations of the current a second. This is less than a maximum result, for experience has shown that telegraph lines can be worked at a much greater speed.

As the apparatus is arranged for transmission, four sets of keys, eight in each set, are placed with their receivers upon a table, each receiver having a continuous strip of paper for recording. A clockwork movement, actuated by a weight and regulated by a conical pendulum, serves as the motor of all the receivers. The keys, as well as the receivers, are connected with the earth wire, and with the line wire in the latter case, through the distributor.

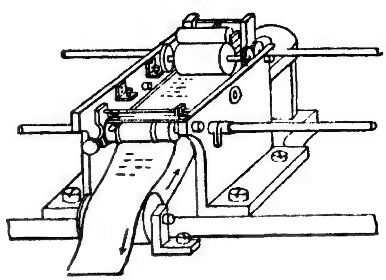
The distributor, Fig. 1127, is the principal part of the instrument. During four equal intervals of time it directs the current of the battery successively toward each of the four receivers of the receiving station. $o\,o$ is a disc of metal, fixed and insulated. It has forty-eight divisions, twelve to the quarter of the circle, of which eight, grouped two and two, are connected to the earth. There are, thus, four cables of eight wires each, which start from the four sets of keys and end in the distributor. The groups or divisions are therefore sixteen in number, separated by intervals. The first half of a group, $\frac{1}{48}$th of a revolution, gives a short contact; the entire group to one of double the length. An elastic contact spring, mounted upon the axis, traverses the circumference of



the disc, and successively connects the four keys and four receivers with the line, so that the current transmitted or received during the passage of the spring over one of the quadrants, is directed through the receiver to which it corresponds. Each operator thus has the line at his disposal during a quarter of a revolution. The transmitter is composed of eight keys, four black and four white, which are connected between the battery and the earth. The black keys represent dots, and the white keys dashes, starting from the left key. As soon as the rotating contact spring, in its movement, passes over that section of the disc to which the keys depressed are connected, the signal or letter is transmitted, the spring passing to the next quarter section, which is connected with the next set of keys, manipulated by another operator, and so on, with all the sections. Attached to each of the keys is an eccentric, the use of which is to raise after each letter a smaller rider, and this, falling by its own weight, produces a tick, beating the measure, to which each operator works.

Each receiver has for its printing mechanism, Fig. 1127*, a section of a helix, resembling an elongated spiral. This may be more easily understood by supposing a cylinder having upon its surface a raised rib extending spirally over its entire length. As the contacts from the sets of keys are placed in a straight line over this cylinder, only one key can be put into connection with the spiral rib at the same time. The helix of the receiver and the rubbing contact of the distributor make their revolutions in the same time, and from the same starting point. An inking wheel revolves freely on each of the helices. The letters appear transversely upon the strip at right angles to the ordinary Morse characters, the paper being raised to the writing helix by the armature of the electro-magnet over which it passes. This transverse disposition of the letters presents a double advantage; it avoids confusion between consecutive letters, and reduces considerably the length of the paper band used for each despatch.

1127*.



Multiple transmission in this case depends upon identical revolutions, in the same time, of certain portions of the apparatus at distant stations. This is effected by the aid of a conical pendulum and a regulating system, by which a correcting current is transmitted every second; and it is arranged that the line should be put to earth at both extremities after each emission of the current.

Construction of Submarine Cables.—The materials employed in the construction of underground or submarine cables comprise the copper required for the core, the insulating coating, whether of guttapercha or indiarubber, and outer protections of hemp with various kinds of sheathing. The data for ascertaining the weight in pounds of copper wire of given diameter will be found under the head of Electrical Testing. In designing a strand of a given diameter, the weight of each wire must be taken separately, and the total weight will be the weight of the strand. Formulæ given for weights of strands are only approximate, as they can be correct for only one kind of strand. Strands for cables are very various in construction, consisting generally of an outer circle of wires around a central wire of the same or larger size than those of the circle. A second circle of wires sometimes surrounds the strand thus formed, when great flexibility is required, with large diameter. As it is essential that the outer circle of wires should fit accurately upon the central wire, the outer diameter of the strand being generally given, it remains to determine the size of the central wire, and the number of the surrounding wires. This is usually effected by the following Table I., calculated from a table of polygons. The table also serves to determine the inner and outer diameter of iron-wire sheathing. Multiply the diameter of the wire by the constant corresponding to the number of wires around the central wire. The diameter of the wire may be in mils, inches, or millimetres. The inner diameter of an iron-wire sheathing, or of the outer circle of copper wires, may be obtained from the outer diameter by subtracting the diameter of the wire.

TABLE I.—DIAMETER OF IRON SHEATHING.

No. of Wires.	Outside Diameter.	No. of Wires.	Outside Diameter.	No. of Wires.	Outside Diameter.	No. of Wires.	Outside Diameter.
3	2·155	10	4·236	17	6·442	24	8·661
4	2·414	11	4·549	18	6·759	25	8·979
5	2·701	12	4·864	19	7·075	26	9·296
6	3·000	13	5·179	20	7·392	27	9·614
7	3·305	14	5·494	21	7·709	28	9·931
8	3·615	15	5·810	22	8·027	29	10·249
9	3·924	16	6·126	23	8·344	30	10·567

The diameter of the core having been determined, and the nature of the strand, the dielectric or insulating material needs consideration. Much discussion has arisen amongst the advocates of the various insulating materials, but the use of guttapercha has gradually extended until this material is that most largely employed as an insulator. Its advantages are durability and almost perfect freedom from change when immersed in water, out of contact with air or oxidizing influences. As a dielectric, its various qualities differ amongst themselves more than other insulators. Cheap guttas, as a rule, are very highly insulating, are mechanically very brittle, and have high inductive capacity. These gums are also generally in a high state of oxidation, and contain a large proportion of other gums than guttapercha. By chemically separating these gums from the guttapercha, the purified percha is found to have properties that are very similar in all samples precipitated from varying kinds of the commercial article, but that still are not identical in the sense that would be imputed to a metal separated from an alloy. This variation probably occurs from the varying rate of oxidation, since guttapercha will oxidize in a moist atmosphere at about the same rate as the metal lead. As it oxidizes, so it increases in resistance; but a curious phenomenon is that, whilst the oxidized product is by itself a substance having lower inductive capacity than the true guttapercha, the compound of guttapercha and oxidized products is of higher inductive capacity; a fact that fully illustrates the accuracy of C. Maxwell's reasoning as to the properties of insulating materials, as regarded from the electro-magnetic theory of light, a theory that finds extension in the fact that the most transparent varieties of guttapercha, as well as of indiarubber, are the most highly insulating. The various qualities of guttapercha are usually blended in manufacture, to obtain medium effects, electrically and mechanically. It is a popular error to suppose that highly insulating guttas are the most valuable, for as a rule these are mechanically

brittle, and have but little electrical durability. Moderate insulation is sufficient for any ordinary wire, and when this has been attained, attention should be directed, preferably, to consideration of the inductive capacity, than to further increase of the insulation resistance, because the inductive capacity in conjunction with the conductor resistance regulate the speed of transmission, which is independent of the insulation when the last is sufficient.

During manufacture, in that stage termed mastication, guttapercha admits of considerable modification of its inductive capacity. Given a temperature sufficient to maintain the gutta easily masticated, the inductive capacity decreases generally with the length of the process of mastication, until a limit is reached at which the capacity commences to increase. Guttapercha should never be masticated to this limit, because its electrical properties are at about this time liable to sudden variations, or departures, from the normal quality of the sample under treatment. In cases where the limit is attained after eighteen hours' mastication, the process should not be continued longer than twelve hours, as when deterioration sets in, its progress is very rapid.

Admixtures have been proposed to guttapercha to increase its insulation resistance, and to decrease its inductive capacity, but the use of none of the ingredients suggested has met with extended application, exception being made with regard to paraffin and other members of the coal-tar series. In view of the approaching scarcity of the guttapercha plant, attention might be bestowed upon this subject with advantage.

Guttapercha weighs about 61 lb. a cubic foot. The resistance of a cubic knot of guttapercha averages about 2100 megohms at 75° F., and its capacity about 0·0687 microfarad. The weight of guttapercha in a knot of core is $\frac{D^2 - d^2}{486}$ lb., where D is the outer and d the inner diameter of the guttapercha sheath in thousandths of an inch. The diameter of a guttapercha core with solid conductor weighing w lb. a knot, and guttapercha weighing W lb. a knot, is $\sqrt{54 \cdot 3\, w + 486\, W}$ in $\frac{1}{1000}$ in. The ratio of the weights and of the diameters of guttapercha may respectively be obtained from Table II., which for practical use includes the logarithm of the ratio of the diameters; these logs. may be increased by 0·03342 for 3-strand and 0·00119 for 7-strand conductors.

TABLE II.—RATIOS OF WEIGHTS AND DIAMETERS: GUTTAPERCHA WIRES.

$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$	$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$	$\frac{W}{w}$	$\frac{D}{d}$	Log. $\frac{D}{d}$
0·75	2·78	0·44404	1·04	3·21	0·50651	1·33	3·60	0·55530
0·76	2·79	0·44560	1·05	3·22	0·50786	1·34	3·61	0·55751
0·77	2·81	0·44871	1·06	3·23	0·50920	1·35	3·63	0·55991
0·78	2·82	0·45025	1·07	3·24	0·51055	1·36	3·64	0·56110
0·79	2·84	0·45332	1·08	3·26	0·51332	1·37	3·64	0·56110
0·80	2·85	0·45484	1·09	3·27	0·51455	1·38	3·65	0·56229
0·81	2·87	0·45788	1·10	3·29	0·51720	1·39	3·67	0·56467
0·82	2·89	0·46090	1·11	3·30	0·51851	1·40	3·68	0·56585
0·83	2·90	0·46240	1·12	3·31	0·51983	1·41	3·69	0·56703
0·84	2·92	0·46538	1·13	3·32	0·52244	1·42	3·71	0·56937
0·85	2·93	0·46687	1·14	3·34	0·52375	1·43	3·72	0·57054
0·86	2·95	0·46982	1·15	3·35	0·52504	1·44	3·73	0·57171
0·87	2·96	0·47129	1·16	3·36	0·52634	1·45	3·75	0·57403
0·88	2·98	0·47432	1·17	3·38	0·52892	1·46	3·76	0·57519
0·89	2·99	0·47567	1·18	3·39	0·53020	1·47	3·77	0·57634
0·90	3·01	0·47857	1·19	3·40	0·53148	1·48	3·78	0·57749
0·91	3·02	0·48001	1·20	3·42	0·53403	1·49	3·80	0·57978
0·92	3·04	0·48287	1·21	3·43	0·53529	1·50	3·81	0·58099
0·93	3·05	0·48430	1·22	3·44	0·53656	1·51	3·82	0·58206
0·94	3·07	0·48714	1·23	3·46	0·53908	1·52	3·84	0·58433
0·95	3·08	0·48885	1·24	3·47	0·54033	1·53	3·85	0·58546
0·96	3·10	0·49136	1·25	3·49	0·54283	1·54	3·86	0·58659
0·97	3·11	0·49276	1·26	3·50	0·54407	1·55	3·87	0·58771
0·98	3·12	0·49415	1·27	3·52	0·54654	1·56	3·88	0·58883
0·99	3·14	0·49693	1·28	3·53	0·54777	1·57	3·89	0·58995
1·00	3·15	0·49831	1·29	3·54	0·54900	1·58	3·90	0·59106
1·01	3·16	0·49969	1·30	3·55	0·55020	1·59	3·91	0·59218
1·02	3·18	0·50343	1·31	3·57	0·55267	1·60	3·92	0·59329
1·03	3·19	0·50379	1·32	3·58	0·55388			

With increase of temperature, guttapercha, like all other gums used in commercial electricity, decreases in resistance. If w' is the resistance of guttapercha at $t'°$ F., and w'' the resistance at $t''°$ F., then

$$\log. w'' = \log. w' - (t'' - t') \log. 0 \cdot 0399.$$

At high temperatures the electrical resistance as well as the mechanical strength of guttapercha is permanently injured.

The electrostatic capacity in microfarads of a guttapercha cable is a knot

$$= \frac{K}{\log. D - \log. d},$$

where K varies from ·1800 to ·1400, the lower number corresponding to a lower standard of insulation.

The insulation of any guttapercha cable may be calculated from p (log. D − log. d) in megohms a knot, where p varies from 700 to 300, according to the quality of the guttapercha.

Where guttapercha covered wire is to be immersed in water, it should receive at least two coverings of gutta, both to diminish risk of fault, and to prevent percolation of water directly through a small hole that might be continuous between outside and the conductor. As a rule, the first coverings are of superior qualities of gum.

Next to guttapercha as an insulator, the most frequently used is indiarubber. As an insulating system, indiarubber is far more complicated than that of guttapercha, because indiarubber alone is never used to completely insulate wires. Generally, a coating of brown or natural rubber is wound spirally upon the conductor, and this is surrounded by a separating coating of indiarubber with which oxide of zinc and French chalk has been masticated, succeeded by a final coating or jacket of indiarubber containing a large percentage of oxide of lead and sulphur. Thus prepared, the core is vulcanized, that is, exposed to high temperature and steam pressure. Under the head of Indiarubber manufacture, this process will be found detailed. The copper wire of the conductor must when inserted in a sheathing of indiarubber, always be tinned, because copper and indiarubber in contact determine a chemical action which results in the rubber becoming viscous, and of no electrical or mechanical value. Cores constructed as described are said to be of Hooper's material, and are used in situations exposed to variations of climate or high temperature. The use of this material does not seem to extend, since it is not reliable according to some authorities, and is of greater cost, but in some situations where guttapercha would be soon destroyed this core has given excellent results, and has proved especially serviceable for torpedo cables, or occasional work subject to be alternately wet and dry.

Hooper's material weighs about 78½ lb. a cubic foot. The resistance of a cubic knot is 43,950 megohms at 75° F., and its capacity about 0·0543 microfarad. Its electrostatic capacity is

$$= 2\cdot7 \frac{0\cdot0543\, l}{\log. D - \log. d} \text{ for } l \text{ knots.}$$

To overcome the difficulty of serving the conductor with such varied materials, it has been tried to pass the wire through a composition of ozokerit and indiarubber masticated together. This mixture has given very good electrical results, but has the disadvantage that it will not adhere to the wire. Kerit, a vulcanized compound of indiarubber and cotton-seed oil, has been largely used for office and leading wires.

A method of laying underground wires has been carried into practice by C. Brooks of America, which differs entirely from any other system of insulation. Cotton-covered wires are laid in a tube, which is then filled, and maintained full, from reservoirs of petroleum oil. Wires thus laid are stated to be free from inductive influence upon each other, and to afford good communication for the telephone. Underground wires are usually multiple core cables, bound together by a sheathing, and laid in a trough or ditch.

The next stage of preparing a cable to that of insulating the conductor is to protect the core with a covering of hemp. The hemp serves generally as a pad to a sheathing of iron wires, which are again served with asphalte in some cases. Given the area of section of the cable filled with hemp and asphalte, it is usual to ascertain the weights required of each material required for a knot of cable from tables similar to III. and IV.

TABLE III.—AREA OF SECTION INSIDE IRON SHEATHING.

No.	a	No.	a	No.	a	No.	a
3	0·04031	10	4·55262	17	16·84500	24	36·94514
4	0·21460	11	5·83145	18	19·23759	25	40·44176
5	0·54238	12	7·26916	19	21·78931	26	44·10753
6	1·02728	13	8·86608	20	24·50018	27	47·93245
7	1·67041	14	10·62211	21	27·37019	28	51·91656
8	2·47223	15	12·53727	22	30·59935	29	56·05978
9	3·43292	16	14·61157	23	33·58768	30	60·36216

Area of section inside iron sheathing = $d^2 \times a$, where a is constant of single wire corresponding to the number of wires.

TABLE IV.—AREAS FOR ASPHALTE CASINGS.

No.	k	No.	k	No.	k	No.	k
3	2·396505	10	12·406509	17	30·196771	24	55·784694
4	3·356194	11	14·470727	18	33·374750	25	60·070713
5	4·469373	12	16·693936	19	36·711869	26	64·527882
6	5·739672	13	19·076255	20	40·208138	27	69·138201
7	7·168203	14	21·617684	21	43·863537	28	73·907700
8	8·755420	15	24·318243	22	47·678106	29	78·836319
9	10·501509	16	27·177942	23	51·651835	30	83·024098

To obtain the sectional area of the space included between the core and a single row of sheathing wires, multiply the square of the diameter of the wire, in any measure in which it is desired that the result shall be, by 0·7854 and by the constant a, Table III., corresponding to the number of wires in the sheathing. From this must be subtracted the product of the square of the diameter of the core, in the same measure, multiplied by $\frac{\pi}{4}$ or ·7854.

To obtain the sectional area between two layers of iron sheathing, in double sheathing, calculate as before for the outer circle of wires, and from the result subtract the product of the square of the diameter of a single wire of the inner circle into 0·7854, and into the constant k, taken for the corresponding number of wires in Table IV.

Then, as 1 cwt. of Italian or Russian hemp occupies 4928 cub. in., and as there are 73,044 cub. in. a knot length of 1 in. sectional area, $\frac{73,044}{4928}$ or 14·822 will be the constant by which the sectional area in inches is to be multiplied to give the weight in a knot, in cwts., of Italian or Russian hemp required. The constant for tarred hemp is 21·038, and for Manilla, 15·528. If the area is taken in square millimetres, the constant to reduce to cwts. a knot is for

Italian or Russian hemp	·0230
Tarred „ „	·3260
Manilla „ „	·0241

If the area is in square millimetres, and the weight is required in kilogrammes a knot, the constant for Italian hemp is 1·1685; tarred hemp, 1·6261; Manilla, 1·2243.

The weight of asphalte required to case a knot of core to a given outer diameter, may be obtained, in cwts., from the sectional area in inches by multiplying by 36. If the area is in millimetres, the constant for cwts. a knot will be ·0558, and for kilogrammes a knot 3·3928. The asphalte area is obtained by deducting from the square of the outer diameter multiplied by ·7854, the square of the diameter of a single sheathing wire multiplied by the constant k, in Table IV., corresponding to the number of wires. These and the preceding constants will decide the weight or dimensions of any ordinary core or cable.

Land Line Construction.—In the construction of an overland line of telegraph, the practice will always vary with the country through which the wire passes, and will be regulated by the cost of transport of the poles and other materials. But the suspension of the wire involves fixed principles, when the breaking strain is known. If T is the breaking strain of the wire, w the weight of unit of length of the wire, L the length of wire that itself can support without breaking, then $L = \frac{T}{w}$ is a constant for the same kind and quality of wire, depending only upon the unit of length adopted. With ordinary soft iron telegraph wire L = 3·3 miles. If t is the working strain of the wire, l the length of the wire whose weight is equal to its working strain, and z the factor of safety, so that $t = \frac{T}{z}$ and $l = \frac{L}{z}$, then $l = \frac{t}{w}$. When $z = 4$, $l = 4400$ ft. for soft iron wire. All telegraph wires are suspended with a certain dip or sag, which practically is in feet, $\left(\frac{a}{400}\right)^2 \times 2{\cdot}56$, where a is the span in yards. For the maximum working span the dip should be $= \frac{a}{3}$.

Table V., in addition to that at p. 2987 of this Dictionary, is of service when dealing with iron wire, it being premised that the resistance a mile of No. 1 is about 5 ohms at 80° Fahr.

TABLE V.—IRON WIRE.

B. W. G.	Diameter in inches.	Weight a Yard in Pounds.	Breaking Strain of Soft Iron Wire in Pounds.	Ratio of Resistance to that of No. 1 Wire.	B. W. G.	Diameter in inches.	Weight a Yard in Pounds.	Breaking Strain of Soft Iron Wire in Pounds.	Ratio of Resistance to that of No. 1 Wire.
1	0·300	0·6875	4000	1·000	9½	0·149	0·1704	900	4·054
2	0·280	0·5990	3400	1·148	10	0·140	0·1497	820	4·592
3	0·260	0·5165	2900	1·331	11	0·125	0·1195	650	5·760
3½	0·250	0·4800	2700	1·440	12	0·110	0·0924	510	7·438
4	0·240	0·4400	2500	1·562	12½	0·105	0·0852	450	8·163
5	0·220	0·3700	2200	1·860	13	0·095	0·0705	400	9·972
5½	0·210	0·3409	2000	2·041	14	0·085	0·0551	350	12·457
6	0·200	0·3056	1800	2·250	15	0·075	0·0429	300	16·000
7	0·185	0·2615	1520	2·630	16	0·065	0·0322	200	18·367
8	0·170	0·2210	1200	3·114	17	0·057	0·0284	150	21·302
9	0·155	0·1836	950	3·746					

In any straight line the whole vertical pressure on the supports is equal to the whole weight of the wire on the line. When the supports are on the same level, and the spans are equal, the vertical pressure on any one support is equal to the weight of wire in one span. In erecting a line in which the wire is not fastened at each insulator, the case is one of a chord passing over smooth pulleys, and the strains along the wire on opposite sides of the support are always equal. The

resultant horizontal strain, if any, is $P = (\cos. i - \cos. i')$, where i and i' are the angles made by the horizon on opposite sides of the support. If the supports are on the same level, and the spans equal, then the angles will be equal and the resultant horizontal strain nil. If the supports are not on the same level, the distance these are to be set apart, in order that i equals i', may be calculated.

R. S. Brough has given the following formulæ for the strain at angles. Let θ be the angle contained by the wire and ϕ the supplement of this angle, R the resultant strain due to the wire is $2\ t \cos. \frac{\theta}{2}$, or $2\ t \sin. \frac{\phi}{2} = t \sqrt{2\ (1 - \cos. \phi)}$. By these formulæ the maximum angle admissible with an insulator of given strength when employed to support a wire of given weight can be calculated, thus $\phi = 2 \sin.^{-1} \frac{R}{2\,t}$. If a radius of 57·3 ft. is measured from the bottom of the post, the number of feet in the chord will give the number of degrees in the angle with sufficient accuracy.

The horizontal pull on a terminal insulator due to the wire is $P = t \cos. i$. The value of t has been given as $= \frac{T}{z}$.

The strength of a post depends on the form of its cross section and upon the material. If P be the resultant strain at right angles to the post, due to whatever cause, and h be the height of the centre of pressure above the ground line, the strength m required at the ground line must be not less than $P \times h$. If z is the factor of safety, then $\frac{m}{z} = P . h$. If d is the depth in the direction of the strain, and b the width of the post at right angles to the strain, generally $m = k \frac{f}{d}\ b\, d^3$ for solid posts; $m = k \frac{f}{D} (B\, D^3 - b\, d^3)$ for hollow posts of uniform thickness, where k is a coefficient for cross section, and f for materials. For squares and cross angles, $k = \frac{1}{24}$. For ellipses and circles, $k = \frac{\pi}{32} = \frac{1}{10 \cdot 2}$. In the case of thin hollow posts, $m = 2\ k . f . t . D\,(D + 3\ B)$, where t is the thickness of material. In the Indian Telegraph Department the following values are adopted for f, as given by Clark and by Rankine;—

		Foot tons a sq. in.
Wrought Iron:	Solid bars and circular welded tubes	18 to 20
	Circular riveted tubes of plate iron, with transverse joints, double riveted	13
	Plate beams	18
Cast Iron:	Solid bars	13
	Tubes	11
Wood:	Fir, Red pine	3 to 4
	„ Spruce	4 „ 5
	„ Larch	2 „ 4
	„ Teak	6 „ 9

If a post is to be of uniform strength throughout, the following may be the proportions. Let x be the depth of the post in the direction of the strain at the ground line, b its width at right angles to the strain, d its depth at the top, then $P \times h$, as before, $= k . \frac{f}{x}\ b\ x^3$, $d = \frac{x}{2}$ if the breadth b is constant; $d = \frac{3}{2} x$ if the breadth varies with x, for solid posts. For thin hollow posts of uniform thickness, $P\ h = 2\ k f t x\ (x + 3\ B)$.

$$d = \frac{x^2}{2\,x + 3\,B} \text{ if B is constant; } d = \frac{x}{2} \text{ if B varies with } x.$$

When a post is insufficiently supported by its own rigidity, it is stayed to the ground or strutted to another post. The resultant moment at the ground line is $m' = m\,P . h . \frac{1}{\sec. a}$, where P is the horizontal strain upon the post, and h the height above the ground at which P is applied, and a the axle of slope, if any, of the post, away from the directions of the strain. The stay should always be fixed in the plane in which the resultant strain is to be met. If the resultant strain in one direction is R and in another S, making an angle ϕ with the former direction, and the total resultant strain T, which makes an angle θ with the first direction, then

$$T^2 = R^2 + S^2 + 2\,R\,S \cos. \phi; \text{ and } \sin. \theta = \frac{S}{R} \sin. \phi.$$

Telegraph lines in exposed situations must be constructed with allowance for the pressure of prevailing winds. A safe maximum wind pressure to be allowed for is 50 lb. on the square foot. The pressure on a semicircular surface is practically three-fourths of that on a flat surface at right angles to the current, although theoretically it is only two-thirds. The strain on the wire at the insulator from this cause is nearly

$$r_1 = \frac{s^2 \sqrt{u^2 + t^2}}{8\,d},$$

where s is the length of span, u weight of wire for a unit of length, and t the pressure for the same unit. If r is the original strain, then this new strain is

In 100 yards span, changes of temperature of 6° F. will cause the dip to vary about 1 in. The following dips in feet are calculated to be used safely with the corresponding spans in feet at quarter breaking strain of soft iron wire.

TABLE VI.—DIP OF SOFT IRON WIRE AT QUARTER BREAKING STRAIN.

Span.	Dip.	Span.	Dip.	Span.	Dip.
ft.	ft.	ft.	ft.	ft.	ft.
225	1·33	1050	31·59	2100	129·81
240	1·64	1125	36·31	2175	139·56
264	1·98	1200	41·36	2250	149·78
300	2·56	1275	46·76	2325	160·40
330	3·10	1350	52·51	2400	171·43
375	4·00	1425	58·60	2475	182·95
450	5·76	1500	65·04	2550	194·80
525	7·85	1575	71·62	2625	207·13
600	10·26	1650	79·00	2700	219·50
675	13·00	1725	86·52	2775	233·20
750	16·05	1800	94·41	2850	247·00
825	19·44	1875	102·67	2925	261·20
900	23·15	1950	111·31	3000	276·00
975	27·20	2025	120·33		

If steel or hard iron wire is used, the dip will be inversely proportional to the breaking strain.

In the Indian Telegraph Department, the unit is taken for iron wire at 25 lb. a mile, and the number n of the wire is found by dividing the weight of a mile in pounds by 25, or $n = \cdot05$ W, where W is the weight of a mile in pounds. The diameter of the wire in inches is $\frac{\sqrt{n}}{23\cdot5} = \cdot0425\sqrt{n}$, and its sectional area is $\cdot0014194\ n$. The resistance at 80°, the standard temperature for India, is in ohms a mile $\frac{\cdot252}{n}$; and the breaking strain in pounds is $83\cdot3\ n$, or $3\frac{1}{6}$ W.

The strain on a terminal insulator in pounds is $21\,n$; and on an angle insulator $42\,n \sin.\frac{\phi}{2}$, where ϕ is the supplement of the contained angle. The number of miles to a ton of wire is $\frac{85}{n}$ and to a cwt. $\frac{4\cdot25}{n}$. These units are easily adaptable to any other system.

Submersion of Submarine Cables.—The method of laying submarine cables has been described in this Dictionary under the head of Telegraphy. Although some modifications in machinery for laying cables and for picking them up have been introduced on cable ships, these do not call for description, and are of that nature which the exigencies of the case have required.

When coiling a cable on board ship, a length of about 40 fathoms is left out for splicing on to any other length of cable. The cable is then passed into the tank, and the coiling is commenced from the outside towards the cone of the tank. The cable is then returned across the flake to the outside of the tank. At every mile, a mile mark is tied on to the cable, and consists usually of a piece of punched guttapercha. The position of a joint in the core is marked by red paint on the outside of the cable. Water is run into the tank as the cable is coiled away, and kept to the level of the working flake. The second flake from the bottom of the tank is usually marked to call attention for preparing to change tanks. Compounded cables have every flake whitewashed to prevent sticking. When tanks are to be changed, the transition from one tank to another is effected in the following manner;—When about a mile from the bight or what was the bottom end of the coil in the tank, but which has been spliced to the running end of the next tank, all hands are called to work, the speed of the vessel is decreased, and the weight taken off the brake of the drum. When about ten turns of cable are left in the tank, the cable is laid in the trough leading to the next tank. In picking up from a buoy, the vessel advances stem on to the buoy and lowers a boat. After removing the flag and the staff from the buoy, a chain is run from the steamer to the buoy chain, and a second rope to the buoy itself. The chain is carried to the picking-up machinery, generally a powerful steam winch, and the cable hauled in. During the hauling in of a cable from deep water, the strain is frequently sufficient to give an indicated length of 3 per cent. more than that recorded during manufacture or paying out. The paying-out gear and picking-up drum should be in line with each other, so that when it is required to work from the stern, the power of the picking-up winch can be utilized forward.

In picking up, the strain on the grapnel rope may be calculated from the following formula ;—T is the strain on the grapnel, add t the strain on the cable when raised through the height h from the bottom of the sea. $2\,k$ is the length of the cable raised, $2\,x$ the horizontal projection, and V the weight in water of one foot of cable; then

$$k = \sqrt{x^2 + h^2}.$$

If q is the ratio of slack to length paid out; $q = \frac{k}{x} - 1$, and $k = (q + 1) x$. The strain on the grapnel $T = 2\,x\,k = 2\,v\,h\,.\,\frac{1 + q}{\sqrt{q^2 + 2q}}$.

The strain on the cable,

$$t = \frac{T}{2\,\sin.\phi} = \frac{v\,k^2}{h} = v\,h\,.\,\frac{(1 + q)^2}{q^2 + 2\,q},$$

where ϕ is the angle of the sides of the bight. If the cable end is sufficiently free to slide on the bottom, q becomes infinite, and $T = 2\,v\,h$, or $t = v\,h$. If the end of the bight were absolutely fixed, the other limit of the strain would be obtained. With a cable having a weight of 1 ton a knot or a weight in water of about 0·001 ton, the following are the multipliers of the height h;—

With the slack q of	1 per cent.	2 per cent.	5 per cent.	10 per cent.
The strain T on the grapnel is	0·0142	0·0102	0·0064	0·4048
„ t „ cable is	0·0504	0·0260	0·0102	0·0058

A cable of 3½ tons, paid out with 5 per cent. of slack, raised from 150 fathoms, would give a strain upon the grapnel of 3·5 × 150 × ·0064 = 3·36 tons.

A length of cable, hanging vertically in water, which it can itself support before breaking, is the measure or modulus of tenacity of the cable. In practice it is considered perfectly safe to lay the cable in a depth equal to one-third that giving the breaking strain. This allowance does not take into account accidental increase by friction, or by the paying-out machinery, or from the pitching of the ship, nor does it provide for the greatly increased strain that will occur if it is required to pick up. It is not advisable to lay the cable in a depth exceeding $\frac{1}{10}$ of the modulus. Maximum of strength, with low specific gravity, are, for evident reasons, essential properties in a good cable. The strength of the cable depends upon the dimensions of the iron covering to a far greater extent than upon the core, and the strength of the cable is probably not increased by using a quantity of hemp, although trials with hemp-covered wire seem to prove, that the breaking strain of the cable may be considered equal to that of good hemp and iron combined. Increasing the quantity of hemp gives the cable lower specific gravity and larger volume, diminishing the strain during submersion, and causing the cable to sink slower by exposure to a greater resistance of water.

A cable weighing v lb. a foot in water, and v^1 lb. in air, will sink vertically in water with a velocity h, and this velocity will be determined by $v = c\,h^2$ or $v^1 = c^1\,h^2$. c and c' are constants of the resistance of the water to displacement, and of the resistance of the water on the cable, which may amount to 80 lb. a knot. The velocity at which the cable will sink can be approximated, by supposing the vessel to move with uniform speed h^1, through a horizontal space A B in a unit of time, and that during this time the cable moves through the water parallel to its starting position a corresponding distance. The velocity of sinking will be represented by a line falling vertically from A upon the second parallel. Let the angle that the cable makes with the surface $= \phi$. The resistance of the water at right angles to the cable is for each foot $= c\,d\,h^2 \sin.\,2\,\phi$, where d is the diameter of the cable. If the speed of the ship is h^1, the angle of immersion will be determined by $h^1\,t \sin.\,\phi$. The angle of immersion is directly as the velocity of sinking and inversely as the velocity of the ship. Cables have been paid out at a rate of eight knots an hour, but this high speed prevents the vessel from being quickly stopped in case of kinks or breaks, and five to six knots is a better speed.

The strain t on the cable during submersion, where the cable enters the water, and when there is no tension on the cable at the bottom, is equal to the longitudinal component of the weight of the cable, diminished by the resistance offered by friction, and this strain has to be counterbalanced by the brake on board ship. Let f be the depth of water in fathoms, p the weight in water of 1 foot of cable in lb., h the velocity with which the cable leaves the ship in feet a second, ϕ angle of immersion, k coefficient of friction = 0·007 diameter of cable. 0·06 is the factor for reduction when fathoms and cwts. are used.

The weight of the cable is $v\,l$, and the component along the cable $v\,l \sin.\,\phi = v\,l\,\frac{f}{l} = v\,f$. The friction on the cable is

$$k\,.\,\frac{f}{\sin.\,\phi}\,.\,h^1\left(\frac{h}{h^1} - \cos.\,\phi\right).$$

The strain t is therefore,

$$t = 0{\cdot}06\,f\left(\frac{v - k\,.\,h^1\left(\frac{h}{h^1} - \cos.\,\phi\right)}{\sin.\,h}\right)$$

This strain, however, may be increased by the inertia of the paying-out drum to 10 cwt., when the ship is rolling in heavy weather. When the ship remains stationary the strain t will be equal to the weight of the cable hanging vertically from the ship to the bottom. This maximum strain may be approximate where the cable is paid out without slack. The strain on the cable is necessarily directly as the specific gravity of the cable, and in inverse ratio to the angle of immersion, so that by reducing the angle of immersion, or by giving the ship greater speed, the strain will increase, and the cable is liable to break; but, on the other hand, by increasing the angle the strain is diminished within the limits of a proper amount of slack. Too much slack will cause kinks in the cable, besides being wasteful. The laying of the cable with strain is not for economy, but to overcome the resistance of the water against the sinking of the cable, and to lay it without tension

in the bottom of the sea. The slack is directly proportional to the amount with which the weight of the cable hanging vertically exceeds the brake force, and is inversely proportional to the square of the speed of the ship. If a correct amount of slack is being paid out, the strain on the dynamometer increased by, say 1 cwt., should have no effect upon the number of revolutions of the paying-out drum; but such rough rules are hardly to be depended upon.

Electrical Testing.—This subject divides itself under two heads, factory testing, and the testing of a laid or suspended wire. The latter again includes testing periodically, for the purpose of ascertaining whether the line maintains a normal condition, and testing to ascertain the position of a fault, when communication is partially or wholly interrupted. Factory tests are always the most exact and searching of all tests to which a line is subjected, for the reason that it is easy to repair a fault in the factory, whereas, in the constructed line, the repair might involve an outlay that would form no inconsiderable fraction of the whole cost. Suspended lines, when constructed of iron wire, are generally tested for strength before leaving the factory, and are only occasionally sampled to be put under test for conductivity. When the line wire is to be a compound wire, having a steel core covered with copper, every coil is tested for conductivity; and this is necessary, because the annealing of the copper strip forms a non-conductive coating, liable to absorb sulphur or gas, which again reduces the conductivity. Whatever may be the cause of the reduction of the conductivity of the copper strip, after its passage through the annealing furnace, this reduction is very marked, and it frequently occurs that where the furnace is defective, the strip loses so much of its conductivity as to become unfit for use. Generally the metal becomes at the same time brittle. Some manufacturers rely upon a tensile test only, and omit the conductivity test for the copper strip, but this increases risk as the absorption by heated copper of a very small percentage of arsenic or arsenical vapour, will reduce the conductivity of the metal 28 to 40 per cent. Compound wire is also generally tested in samples when tinned, and when ready to be sent from the works.

The only other electrical test applied to materials for land lines is to the insulators. These are placed inverted in a shallow tank containing water, which reaches only to the rim of the cup of the insulator; water is filled into the cup nearly to the rim, and the rim is dried by a gas flame, or, preferably, by a heated metal surface. One pole of a powerful battery is connected to the water in the tank, the other pole being attached to a galvanometer, usually of the reflecting class. A lead is taken from the galvanometer, and dipped by a workman into each inside of the cup of the insulators in succession.

The inspector watching the light on the galvanometer scale rejects those insulators that allow of the indication of a current. Although other methods have been proposed for testing insulators, this original plan is only in use, and its manipulation requires but little skill, and is rapid.

It frequently happens that the engineer, in the charge of a section of line, has to test a few insulators before these are put up to replace those that have become defective, and has not a powerful battery at his command. In that case the edges of the insulator are carefully paraffined or oiled, and a condenser is arranged to be discharged through it in a certain time. If there is no appreciable loss of charge in two minutes, the insulator may always be passed as perfect.

The testing of materials for underground and submarine lines is conducted with very much greater care than in the case of materials for land lines. From every bundle of copper wire a certain length is measured off, weighed, and its conductivity carefully ascertained. The conductivity of copper wire is usually, in England and America, stated in terms of the conductivity of a standard wire weighing one grain a foot.

In earlier underground and submarine lines 80 per cent. was adopted as a reasonable standard, but owing to the great improvement effected in the preparation of this metal for telegraphic use, the standard has been so much increased as to bring about the apparent anomaly of wires having a higher conductivity than pure copper, or more than 100 per cent. This arises from the improvement effected upon the earlier standard adopted, and that it is more convenient to maintain that standard than to introduce a new one. Where a large quantity of wire has to be tested for conductivity, it is more convenient to construct a Wheatstone bridge, having a metre or yard of the wire of known conductivity in one of the arms, than to measure each sample of wire against a resistance coil. In all measurements of this character it is necessary that the standard wire, or resistance coil, should be of copper to avoid temperature effects. It is advantageous, also, to construct the parts of the bridge of unlacquered copper. On the Continent mercury is adopted as a standard, and as this metal is very easily obtained in a state of purity, its use would have an advantage, if it were not for the Peltier or temperature effect, introduced by the metallic difference in the standard and the test wire.

A rod of pure copper 1 m. length and 1 sq. mm. in section weighs nearly 8·95 grammes; its resistance is 1·01642 ohm, at 0° C., increasing or decreasing 0·388 per cent. for each degree of temperature. The resistance of a rod of pure copper of one metre length, and weighing 1 gramme, is 0·14677 ohm, at 0° C. The weight a knot of a telegraphic pure copper wire is 18,430, d^2, d being taken in decimals of an inch; consequently the diameter of a pure copper wire weighing w lb. a knot is $7·366\sqrt{w}$ mils, or thousandths of an inch. The resistance of a knot of pure copper wire weighing w lb. is $\frac{1192·45}{w}$ ohms, or $\frac{1250·4}{w}$ Siemens units, at 75° F.

After the copper wire is tested for conductivity, it usually has to be stranded, and sometimes the strand is covered with a wash of Chatterton's compound before being sent to the covering shop. It tends to prevent waste of material, if the strand is tested for conductivity before it is covered, for the reason that in stranding wire, the single wires are liable to be elongated in the stranding machine, and although this elongation is usually more than compensated for in the unit length, by the extra wire of the helical lay, it occasionally happens, and especially with strands of

numerous wires, that, because of the elongation, the strand does not come up to the standard of the single wire.

During the subsequent stages of covering the wire with guttapercha or indiarubber, or other insulating materials, constant and careful tests should be made as to resistance, and these tests compared, after reduction to a uniform temperature, in order that any increase of resistance may be observed. One advantage of a careful reduction of all the resistance measurements, made with cable intended for a submarine line, is that when the cable is coiled on board ship, its temperature in the tanks may be easily ascertained from its copper resistance, and increase of temperature, that would deteriorate the insulator, be provided for. To correct the resistance of any wire for temperature, where t is the lower and t' the higher temperature, R the resistance at the temperature t, and R′ the resistance of the temperature t', $R' = (1 + (t' - t)\,a)\,R$, for degrees C.; where a is a constant depending upon the metal, usually 0·288 for copper.

The resistance of a knot of copper wire at 75° F. multiplied by 0·5214 will give a resistance of a kilometre of the same wire at a temperature of 15° C.; and conversely the resistance of the kilometre of copper wire at a temperature of 15° C. multiplied by 1·9176, will give the resistance of a knot of the same wire at 75° F.

In measuring the conductivity of a core, as a covered wire is termed in a factory, it frequently happens that the measurements made with the zinc current and with the copper current differ slightly. Where the difference is small and W is the reading with the positive current, and w the reading with the negative current, flowing towards the branches of the bridge a and b, the true resistance r, will be $r = \frac{b}{a} \cdot \frac{w + W}{2}$.

If the difference is greater, which should not occur with a perfect core, the true resistance is $\frac{b}{a}\left\{\frac{w+W}{2} - N\frac{w-W}{2}\right\}$, where $N = \frac{w}{w + W + a}$.

Although in testing a core, the increase of resistance of the conductor is generally regarded as indicating that some strain has occurred, before the conductor has been stranded or covered, it is not to be assumed that decrease of resistance is not an indication of deterioration in the core. A very minute fault in the insulating covering will cause the copper resistance, as measured on the bridge when an earth conductor is used, to appear to be less than the true resistance.

In the factory, besides the measure of the conductivity of copper for core work, part of the business is the measurement of resistance of coils of silk-covered wire, that are intended to be used in resistance coils, or for electro-magnets. As the coils in a resistance box are always double wound, there is no liability to error in their measurement in the ordinary manner; but when the resistance of a coil of wire, wound as an electro-magnet, is to be ascertained, considerable error is sometimes caused by the neglect to observe that the coil, when it becomes a magnet, under the influence of the measuring current, has an effect upon the needle of the galvanometer. An error is very often introduced at stations, by the neglect of observing this effect when measuring the resistance of the coil of a relay, for as it is unadvisable to remove the iron cores from the magnets, the extra current discharge, upon breaking circuit in the bridge, is sufficient to demagnetize the galvanometer needle, or, if not to completely demagnetize it, sufficient to cause appreciable alteration of its magnetic moment. Coils of this character should always be short circuited with a thick piece of wire, before and whilst the circuit is broken. This discharge should also receive careful attention, in measuring copper resistance by deflection on land wires through the relay, as the extra current on the breaking of the circuit, is liable to spring from one convolution to another in the fine wire of the reflecting galvanometer.

It is frequently advantageous to be able to calculate the length, and therefrom the resistance of wire coiled on a circular bobbin. The length is $L = \frac{b}{4\,d^2}(A^2 - a^2)$, where d is the diameter of the wire, including the silk covering, b the length of the bobbin less the thickness of the cheeks, A the outer diameter, and a the inner diameter of the bobbin.

Copper resistances of ordinary lines are usually measured on the bridge, but on long cables subject to earth currents, bridge measurements are very difficult to manage, and require the operator to have some experience of the strength of the earth currents and the line he is testing, in order that his test may be accurate. Many very exact and complicated methods have been proposed for eliminating the effect of the electro-motive force of the earth currents, but as this electro-motive force is variable, the better plan is to include its variations in a series of measurements, and to take the mean of a series in which the electro-motive force is opposed to the constant one of the battery. This method was first introduced by W. Thomson, and consists practically in observing every half minute, for say half an hour, the deflections obtained on a galvanometer from the current of a constant battery, when passed through the cable conductor, the distant end of the cable being to earth. The battery pole is reversed and the observations repeated at the same intervals for an equal length of time. A resistance coil of somewhat similar resistance is then substituted for the cable conductor, and a deflection observed with a positive and with a negative current, this serving as the proportionate standard for the reduction obtained with the cable.

More accurate than to take the arithmetical mean of the cable observations is to employ the following formula, which gives the true or geometric mean, when the positive or negative currents yield different results. If R be the resistance for the use of one pole of the battery, and r the resistance observed with the other, in each of the two corresponding measurements, the true resistance is $= 2\,\frac{R\,r}{R + r}$. It has been proposed to use the cable, when strongly affected with earth currents, as a battery, and to measure its internal resistance by the method proposed by C. Maxwell, but storms of earth currents are rarely of so long duration, in sufficient intensity, as to render this

expedient necessary. The delicacy of the operation is likely to introduce greater error than that arising with the direct method just described.

Whether measuring copper resistance of core or cable, the effect of inductive charge and discharge upon the galvanometer needle must be carefully avoided, and the galvanometer circuit should always remain short circuited for a few instants after the battery circuit, and should be that first closed.

The testing of core and cable includes two other measurements besides that of copper resistance. These are to ascertain the insulation resistance, and the inductive capacity. Insulation resistance is the resistance offered by the insulating material, or dielectric, to the escape of current from the conductor, and its measurement is effected, in the factory, by placing the core or cable under water. One of the ends of the core is carefully insulated by being raised about 2 yards out of the water. This end is cut; about 1 in. of the end of the conductor is laid bare and the dielectric tapered down. The cut part of the dielectric and the bared conductor are then paraffined, and the end carefully suspended, generally on an indiarubber band, to keep the conductor from any surrounding earth connection. The coils for testing in the factory are thus prepared by the tank men, and when the electrician takes them under test, the remaining end is connected to a well insulated lead from the testing room. These leads are connected to a galvanometer, which is also connected to one pole of a powerful battery, and the other pole put to earth. The galvanometer being short circuited, the battery circuit is established, and, at the end of half a minute, the short circuit is removed from the galvanometer, and the deflection, when steady, read off. The deflection gradually decreases, and readings are taken at the end of every minute, for a period of five or seven minutes. The galvanometer is then short circuited, the battery poles reversed, and the operation repeated. The operator ascertains what is the deflection obtained with the same battery when a known resistance of a million ohms is substituted for the coil; the resistance of the insulation in megohms or millions of ohms is then calculated from the following formula,

$$\left(\frac{R\left(\frac{g+s}{s}\right)d}{d'}\right)l$$

where l is the length in knots, d the deflection with the battery and known resistance of R millions units, and d' the deflection with the cores, g being the galvanometer and s shunt resistance. $(R\left(\frac{g+s}{s}\right)d)$ is termed the constant of the galvanometer, and is usually ascertained by each operator when he comes on duty for the day.

In making measurements of this constant, the battery should not be allowed to be too long in circuit with the standard coils, because the intense current causes them to become heated, to alter in resistance, and the measurement to be inaccurate.

The deflection has been stated to decrease during the five or seven minutes' test; this decrease of deflection is due to the phenomenon of electrification or electric absorption, in which the dielectric seems to soak up the electric current. Theories have been brought forward in explanation of this phenomenon, but whatever its cause, it affords the telegraph engineer early indication of a minute fault, otherwise unobservable. Should the readings of the insulation resistance between the first and second minutes not show the usual difference, the coil should always be reserved for future independent testing, as it is almost certain that there is a minute fault. This fault may be broken down by rapid reversals of the current from a powerful battery continued for some hours, preferably when the coil is immersed in water at 75° F.; or it may be tested for with an electrometer. A comparison thus made with guttapercha cores, between the first and second minute reading, will give as valuable an indication of the state of the core as the actual measured resistance, which is only resistance at the particular instant of measurement.

As there are usually several operators working at one time in the testing room, it is necessary to arrange the instruments so that the magnetism of one does not affect that of the other, and especially so that the charge of one lead shall not cause an induced current in the adjacent leads. To prevent this latter interference, the leads are placed in zinc pipes, and these pipes are maintained in good connection with the earth. The testing room should be situate as far as possible from any moving machinery, as well as from the proximity of large masses of iron, such as the tanks.

When the coil is so short as to render its insulation resistance sufficient to reduce the deflection on the galvanometer scale to 20 degrees, the measurement should be by loss of charge. The coil should be charged, then discharged immediately, then charged again, and discharged after t seconds, the capacity S being ascertained in microfarads by the method to be presently described. The insulation resistance I in megohms may be ascertained from the following formula, where C is the immediate discharge, and c that observed after t seconds $I = 0 \cdot 4343 \dfrac{t}{S \log. \frac{C}{c}}$.

The insulation resistance of a condenser is usually measured in this way, and the principle is that leakage of a certain amount of current from a condenser, whether in the form of plates or core, in a given time, always proceeds logarithmically or at compound interest rate.

Line Testing and Testing for Faults.—Line testing is usually, even on the chief cables, considered of small moment, and is too often conducted in a perfunctory manner. That a telegraph line should be frequently and accurately tested is essential, not alone because this course may prevent total interruption, but that when a fault occurs the location may be stated with greater certainty. With a properly arranged testing board, the tests for conductivity and insulation are very quickly and easily made in the manner described in the preceding section.

In line testing there may be distinguished the measured circuit resistance, including instruments C, the measured conductor resistance H, and the measured insulation resistance I. L. Schwendler has pointed out that all the faults in a line resolve themselves into a resultant fault, and that if L is the true conduction resistance of whole line, i the true insulation resistance, and l the true conduction resistance up to the resultant fault, r the true resistance of receiving instrument at distant station,

$$i = \sqrt{\frac{(I - C)(I - c)r}{C - c}}, \qquad L = I + \frac{(I - C)r}{C - c} - 2i, \text{ and } l = I - i.$$

$\frac{l}{L}$ should be positive and less than unity. While $l = \frac{L}{2}$, $i = \sqrt{I(I - c)}$, $L = 2(I - i)$; and $\frac{I(C - c)}{I - C}$ should be equal to r.

If the line is n miles in length, the insulation for a single mile is $n\,i$. And if m is the reduced length of the line in terms of the standard wire, the conductor resistance will be $\frac{L}{m}$ a mile.

For the testing of a faulty line to localize a fault, a well-known system is that introduced by Blavier. Measurements are made with the end of the line to earth at the distant station, w; with the end of the line insulated at the distant station, I; and the true conductor resistance of the line must be known, L. The distance of the fault is then $x = w - \sqrt{(I - w)(L - w)}$. Schwendler gives a similar formula, where C is the measured circuit resistance, dispensing with L,

$$x = I - \sqrt{\frac{(I - C)(I - w)r}{C - w}},$$

being the resistance of the receiving instrument at the distant station.

The latter formula is the more practical. This test is applicable in the case where a second line is not available. If a second and perfect line is to be obtained, the test known as the loop-test is preferable, as it eliminates to a certain extent the error arising from the resistance of the fault.

Every fault has resistance. If the line wire break and fall on the ground, the place of contact, unless very wet, will give considerable resistance; and even with a submarine conductor exposed under water, the surface is insufficient to afford what is technically known as a dead earth, or earth without resistance.

In the following formula for the loop-test, the accentuation of the letters gives the observed resistances in corresponding tests. a, b, are bridge branches; w'' measured resistance with second line looped, w' without observed resistance. The resistance to fault $x = \frac{a'\,b''\,w'' - a''\,b'\,w'}{a''(a' + b')}$.

When $a = b$, $x = \frac{w'' - w'}{2}$.

In measuring the distance of a fault on a cable, the problem becomes difficult, on account of the contrary electro-motive force set up by the sheathing and the copper conductor, the polarization of the broken end by the testing battery, the presence of earth currents, and the absence of a second wire. The following formula, which furnishes indications of the data required, is that arrived at after long experience by several cable electricians, and is reliable always where concordant measurements are obtained. The methods of making each measurement must be determined by the apparatus at the electrician's disposal, but the observations can generally be made by any of the methods previously described.

Let x be the true resistance to the break; R the measured resistance of cable and break; k the capacity corresponding to a unit of conductor resistance, or total capacity divided by total resistance when fault free; f resistance of battery; g of galvanometer; d the discharge deflection from cable; D from condenser of 1 unit capacity.

$$x = R - \sqrt{R^2 - \frac{3d}{Dk}(g + R)(f + R)}.$$

If the resistance of the break were nil, two-thirds of the charge would return to the charging end, but the occurrence is improbable. In the capacity test there will nearly always be a permanent deflection, p, and if the discharge reading d is in the same direction as the permanent deflection, the true discharge $= \sqrt{d^2 - 2dp}$; if in the opposite $= \sqrt{d^2 + 2dp}$.

In land line working, contacts between two lines are very troublesome to locate. Location is generally effected in practice by instructing each station on the line, successively, to disconnect for insulation until the contact is noticed, when it must lie between the station last insulated and the next. Or with contacts between two lines where this practical system cannot be adopted, the resistance is measured with the two ends joined, w'; and with the distant ends insulated, w''. Then

$$x = \frac{w' - \sqrt{L' + L'' - w'\,(w'' - w')}}{m' + m''},$$

where L′ and L″ are the total, and m' and m'' the mile resistance of the two wires in contact.

If a third wire on the same route is available, one of the wires in contact can be put to earth, and the contact localized as an earth by the loop-test.

If the wire remains insulated at the distant end, the relation of the measured to the true insulation resistance of the line will afford an approximation to the locality of the break. If the wire is a cable conductor, and the end becomes sealed by the pressure of a falling body or otherwise, the measured capacity will give the position of the break, but the test is unreliable.

Speed of Transmission.—The speed upon a land line of suspended wires is practically limited only by the condition of its insulations. On any line, submarine or overland, the speed is inversely proportional to the product of conductor resistance into the electrostatic capacity. But in a suspended wire the capacity is scarcely appreciable, and the loss of current is more marked. For comparison the following formula will give an approximation to the capacity, in microfarads for a length of l miles of an overland line, $S = \dfrac{l}{24 \log. \dfrac{4h}{d}}$ where d is the diameter of the wire, and h is the height above ground. By the use of a receiver, in which a strip of paper chemically prepared is employed as record, W. Thomson has seen 1200 words a minute received over 800 miles of actual line.

Owing to the large capacity of subterranean and submarine wires, the speed is incomparable with that of land lines. L. Clark and R. Sabine give the speed of signalling with the mirror instrument, in words a minute, as $n = \dfrac{a}{k\,c\,l^2}$, where a is a constant = 130,000,000 for guttapercha cables, and 176,000,000 for Hooper's cables.

Speed is inversely as the square of the length, since both resistance and capacity have effect upon speed, and involve length in each case. The speed of the Morse recorder is about one-fifteenth that of Thomson's mirror, but the practical limit of Morse working is 300 miles of ordinary cable. In Morse working a dot, apart from cable effect, takes ·27 second at fifteen words a minute.

Expedients have been adopted, described under the head of duplex telegraphy, for increasing speed by neutralizing the discharge of the wires, but these cannot affect the speed in the wire itself. With a line or cable slightly faulty in insulation, artificial leakages apparently increase the speed, by reducing the discharges, but the speed of transmission through the cable itself is reduced only in amount as much as the joint circuit of derivation through the fault reduces the total line resistance.

Miscellaneous Data for Telegraph Testing.—In connection with the escape of electricity, across an insulating sheathing, are certain forms of integration from which the ordinary working formulæ are deduced. If $d\,x$ = thickness of differential cylinder at distance x from longitudinal axis of cable, its resistance will be $d\,r = \dfrac{d\,x}{2\pi\,l\,x\,\lambda}$, and the whole resistance of the length l will be

$$\frac{1}{2\pi\,l\,\lambda}\int_r^R \frac{d\,x}{x} = \frac{\log._\epsilon \dfrac{R}{r}}{2\pi\,l\,\lambda},$$

λ being the specific conductivity. Related to this is the expression for the resistance to the flow of electricity, from a central electrode of radius ρ to the periphery of a regular polygon of n sides,

$$\frac{1}{2\pi\kappa\delta}\left(\log. \frac{r}{\rho} \cdot \frac{4}{3 + \cos. \dfrac{\pi}{n}}\right),$$

r being the radius of the inscribed circle, δ the thickness of the plate.

Although insulation resistance is usually specified in megohms a knot, a mile, at a temperature of 75° F., or 24° C., some electricians prefer to specify a limit to the percentage loss of current. The loss of current is estimated in the following manner. k is the total conductor resistance, g total insulating resistance, S current sent, and R current received.

$$R = \frac{2S}{e^{\sqrt{\frac{k}{g}}} + e^{-\sqrt{\frac{k}{g}}}}$$

The result is independent of the length of the cable, and only dependent on the ratio of the total resistance of conductor and dielectric. The percentage of loss is 100 (1 − R).

The capacity of a cable or subterranean wire is usually compared with that of a condenser whose measure in microfarads is known. Comparison is made by insulating the distant end of the cable, which is connected to, say, the fulcrum of a common contact key. A battery of a few elements is connected to, say, the back contact of the key, and the other pole of the battery is put to earth. To the front contact of the key is connected one of the terminals of a galvanometer, and the other is put to earth. Whilst the key is at rest on the back contact, the cable is being charged, its outer coating, or the water in which it is immersed, acting as the earth-armature of the condenser. When the key is depressed upon the front contact, the cable is discharged, and the galvanometer needle is momentarily deflected. The throw of the needle measures the capacity of the cable, for which a condenser of known capacity is substituted, the throw with this condenser and that with the cable being taken as proportional.

When a cable or coil has its distant end insulated, practically all the charge will return to the charging end. When a cable insulated at both ends is charged by a battery, the potential of the charge will be the same at all points of its length, and if the two ends are put simultaneously to

earth, the charges flowing out of them will be equal; and as the flow is from the middle point of the cable towards the ends, this point will keep its potential a maximum above all other points in the cable length. But with a cable charged with one end to earth, the curve of the fall of potential will be a parabola, two-thirds of the charge returning to the charging end.

When a cable whose farther end is to earth, is charged by a battery whose resistance is small compared with the resistance of the cable, the charge it will take will be directly proportional to its length. If the resistance of the battery is large compared with that of the conductor, the charge the cable will take will be directly proportional to the square of its length. When two or more cables whose farther ends are to earth, are charged so that the strengths of the current flowing through them are the same, the charges will be directly proportional to the square of the lengths.

In the case of a wire eccentrically placed, the electrostatic capacity is

$$\frac{I}{2 \log._\epsilon \dfrac{R^2 - f^2}{R R^1}}$$

where I is the specific inductive capacity, R the inner radius of the conducting sheath, R^1 radius of wire, of which R must be a considerable multiple, f the distance between the axes of R^1 and R. When the wire is concentric, the expression resumes the form $\dfrac{I}{2 \log. \dfrac{R}{R^1}}$ previously given for the capacity. In the comparison of two condensers required for standards, where accuracy is essential, correction is sometimes made for the friction of the air against the needle during the throw: but the correction is inappreciable in galvanometers of ordinary working construction.

The Thomson galvanometer is sometimes, in order to magnify the readings, removed to several times its usual distance from the scale. As the scale is straight, and is tangent to the arc of throw of the beam of light from the galvanometer, a correction is made use of, and C and c being the capacities, D and d the deflections, and z distance of mirror from scale measured in divisions of the scale,

$$C : c :: d\left(\sqrt{z^2 + D^2} - z\right) : D\left(\sqrt{z^2 + d^2} - z\right).$$

Where the compared deflections on a galvanometer are widely different, so that the current strength in one case would cause the deflection to exceed the limit of reading, whilst in the other within that limit, it is usual to shunt off some portion of the current passing through the instrument, by connecting a wire or coil of required resistance between the terminals of the galvanometer. To reduce the current flowing through a galvanometer to its $\frac{1}{n}$th part, a shunt must be inserted, the resistance of which is $\frac{1}{n-1}$th part of g. As has been before explained, the introduction of a resistance in parallel circuit with another resistance reduces the total resistance of the circuit. For this reason, to maintain the total resistance constant, and the flow of current the same as before the introduction of a shunt, a compensating resistance must be put into the circuit whose value will be $g\,\frac{n-1}{n}$ or $\frac{g^2}{g+s}$ where s is the shunt resistance. The use of this resistance is dispensed with in measurement of insulation resistance and electrostatic capacity, because the resistances in circuit are very large, compared with the resistance that it would be necessary to introduce.

In practice some slight error is avoided by selecting the shunt resistance so that the deflections to be compared are nearly, if not identical.

Instead of using the shunt when comparing capacities, the battery pole, connected in the direct method to the key, is put to earth through a resistance. The resistance is so arranged that contact may be made at any part of its electrical length. The points of contact are so chosen that the deflections with the capacities to be compared, coincide. The potentials at the two points are then ascertained, and the capacities are inversely as the potentials. To find the potentials at any point of a conducting series, suppose M N the conductor length, and X an intermediate point. Let m and n be given potentials at M and N, and x the potential at X. If r be the resistance between M and X, r_1 between X and N, and R between M and N $= r + r_1$, then $x = \frac{r_1 m + r n}{R}$. This is the principle of W. Thomson's slide resistance and L. Clark's slide potentometer.

Small capacities are difficult to measure, and can be satisfactorily treated only with a vibrating contact which, by maintaining the deflection constant, enables it more easily to be read. The contact is made to vibrate by clockwork, or a modification of Lacour's phonic wheel, would, it may be suggested, yield good results. The measurements of this description are, however, more fitted for the laboratory than the testing room.

The only other measurement occurring in the testing room is of the specific resistance of the insulating material. It is necessary for the electrician in charge of the core factory to know the electrical qualities of the material in stock, in order that he may instruct as to the proportions of each quality to be used. It would appear easy to test, say, guttapercha in a small sheet of uniform thickness, but the delicacy of the apparatus required has undoubtedly been the hindrance to the introduction of such a test; it is usual to cover a short length of wire as a sample and to test this sample as a coil of core.

From the length of a sample it is frequently necessary to estimate the weights in a knot of cable. For this the following constants are useful;—

Grammes a yard	multiplied by	4·47317	=	lb. a knot.
" foot	"	13·41951	=	"
Grains a foot	"	0·8696	=	"
Oz., avoirdupois,	"	380	=	"
Grammes a metre	"	4·089	=	"
" yard	"	5·146	=	grains a foot.
" metre	"	4·7038	=	"
" "	"	14·115	=	" yard.

Electrical Units.—Units of Resistance.—In order to compare different resistances, a standard of measurement is required, which is called the unit of resistance, Unfortunately, physicists have not yet been able to agree among themselves upon a common standard. Some of them have made use of a very thin copper wire of a certain length and sectional area, others have preferred to make use of wires of gold, silver, or alloys of different metals. The following are some of the principal units;—

Wheatstone's Unit.—Wheatstone constructed, in 1840, the first instrument by means of which definite multiples of a resistance unit could be added to, or subtracted from, a given circuit at pleasure. The standard resistance unit was that of 1 ft. copper wire weighing 100 grs.

Jacobi's Unit.—Professor Jacobi, of St. Petersburg, has suggested various units of electrical resistance. The unit commonly known as Jacobi's was 25 ft. of a certain copper wire, weighing 345 grains.

Siemens' Mercury Unit.—This unit represents, according to the definition of W. Siemens, the resistance of a prism of pure mercury 1 m. long and 1 sq. mm. section, at a temperature 0° centigrade. This unit was first produced in 1860, and resistance coils of German silver wire were copied from it.

French and Swiss Units.—In the telegraph administrations of France and Switzerland, the unit of the resistance coils in use prior to 1867, was equivalent to the resistance of 1 kilom. of the iron wire employed for telegraph lines of 4 mm. diameter. As no exact measurements of overhead lines are required, these units were neither defined nor produced with accuracy, and no standard of temperature was given to enable the units to be reproduced when desirable. In 1867 these units were readjusted to equal ten Siemens units, which is nearly their original value. In French submarine cable work resistance coils adjusted to the Siemens units are employed.

Matthiessen's Unit.—This unit was defined as the resistance of a statute mile of pure annealed copper wire $\frac{1}{16}$ in. in diameter, at 15° C.

Varley's Unit.—This was formerly much used in England. It was originally constructed from a statute mile of special copper wire $\frac{1}{16}$ in. in diameter, but Varley afterwards readjusted it to twenty-five Siemens units.

German Mile Unit.—The first unit of measurement used in the Prussian telegraph service was that of a German mile, 8238 yds., of copper wire, of diameter of $\frac{1}{12}$ in., and its temperature 20° C. Resistances adjusted to this unit were manufactured as early as 1848, but these have since been superseded by coils adjusted to the mercury unit.

American Mile Unit.—The resistance coils used in the United States prior to 1867, employed as a unit a resistance equal to that of one statute mile of No. 9 iron wire. These were prepared at the suggestion of M. Lefferts, then engineer of the American Telegraph Company, by G. M. Phelps as early as 1862. The coils were of No. 36 iron wire, and arranged in sets of decimal numbers, so that the resistance could be read off directly without calculation. These have been superseded by the British Association unit.

The British Association Unit.—This unit was proposed in 1862 by Weber, and afterwards determined with great care by a committee of the British Association, in accordance with the suggestions of W. Thomson. This unit is defined as equal to 10,000,000 $\frac{\text{m.}}{\text{sec.}}$ According to the most trustworthy determinations, it is equal to 1·0486 Siemens mercury units.

Although all these units have been employed, only two of them, the British Association unit and the Siemens unit, are now in use for telegraph measurements. The two units do not, in fact, differ very materially from each other, and in point of actual convenience there is little or no choice. Practically, the British Association unit or ohm may be said to be the recognized standard in use in England and America.

The resistance of a portion of the circuit, or of the entire circuit, expressed by a certain length of a standard wire, is termed its reduced resistance, and the corresponding length of standard wire is termed its reduced length.

Besides the unit of electrical resistance, there are units required to measure potential, current-quantity, and capacity for electrostatic charge. In practice, the unit of electro-motive force is, in England and America, generally that of a Daniell's element, but, on the Continent and in America, where high potentials are to be measured, the Bunsen element is taken as unit. A Daniell cell is stated to be equal to 1·079 volts, the volt being the unit adopted for electro-motive force by the British Association Committee. The deductions made by this Committee were from a purely theoretical conception of electrical motive force, and were obtained from the current induced by the earth's magnetism in a revolving coil of wire of certain dimensions. In practice, although the unit volt of potential is used, measurements are referred to the Daniell cell, the volt value being reduced therefrom by calculation. The volt is equal to 10^8 metre gramme second units of work. The rate of doing work for a galvanic element is $\frac{E^2}{R} = 10^7$ m. g. s. units for 1 volt through 1 ohm,

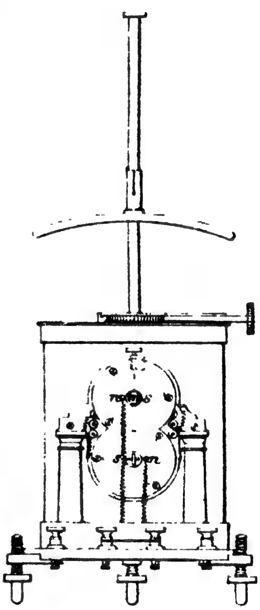
or 1 volt-ohm uses $\frac{1}{3000}$ gramme of zinc and 10^7 absolute m. g. s. units of work a second. 1 volt-ohm is equally 44·24 foot-pounds a minute, or 1 HP. is 746 volt-ohms, and is equivalent to the consumption of $\frac{746}{3000}$ grammes of zinc a second in a Daniell's cell.

The unit of quantity of current is that carried by one volt of electro-motive force through one ohm of resistance in one second, and is termed the weber. A weber is 10^{-2} metre gramme second units of work. The work done in a circuit of resistance r ohms in t second by a curr nt of C webers is $W = 101 \cdot 92\ C^2 r t$ grammetres; and the heat developed in a circuit is $H = 0 \cdot 2405\ C^2 r t$ calories, each calorie being the quantity of heat required to raise 1 gramme of water 1 degree centigrade. One weber of electricity decomposes ·00142 grain of water a second; and the weight of metal deposited from the solution of any of its salts by a current of C webers in t seconds is $n = 0 \cdot 00001\ a\ C\ t$ grammes, where a is the atomic weight of the metal as referred to hydrogen. This formula is sometimes used in the deduction of current strength from an electrolytic bath inserted in the circuit.

For capacity the unit adopted is, in practice, a microfarad, measured from a standard condenser. A farad is equal to 10^{-7} metre second units, and a microfarad is the millionth of a farad. A microfarad is, roughly, about equal to the capacity of one-third of a knot of the Atlantic cables.

Electrical Instruments.—The Thomson galvanometer, Fig. 1128, is made in a variety of forms. The form most in use consists of a base of a round plate of ebonite, provided with three levelling screws; two spirit levels, at right angles, are fixed on the top of this plate, so that the whole instrument can be accurately levelled. Sometimes one circular level only is provided, but the double level is much the best arrangement. From the base rise two brass columns, and between them a brass plate is fixed, rounded off at the top and bottom. Against the plate are fixed the coils, the ends of which are shown by dotted circles. The brass plate has shallow countersinks in its surface for the faces of the coils to fit into, so that they can be put in their correct places without trouble or danger of shifting. Round brass plates press against the outer surfaces of the coils by means of screws, and keep them firmly in place. There are two round holes in the brass plate coinciding with the centre holes in the coils. The coils, Fig. 1129, are four in number, and are wound on bobbins of brass, the wire being coiled thicker towards the cheek of the bobbin which bears against the brass plate. This curving of the section of the coil is in accordance with the law of W. Thomson, to obtain a maximum effect from a minimum quantity of wire. The edges of the coils are covered with shellac, to protect the wire from mechanical injury. Within the holes in the brass plate are placed two magnets *n s* and *s n*, formed of watch spring highly magnetized, connected by aluminium wire, to form an astatic pair of needles. A groove is cut in the brass plate between the upper and lower hole, for the connecting aluminium wire to hang freely in. In front of the top needle is fixed the mirror. The suspension fibre is attached at its upper end to a small stud which can be raised or lowered as required. When pressed down as far as it will go, the needles rest upon the coils, and the tension is taken off the fibre; the instrument can then be moved about without danger of breaking the fibre. One end of each coil is connected with one of the four binding screws in front of the base of the instrument, the other ends being connected to one another through the binding screws. The whole four coils are in the circuit of the two outer binding screws, so that they all act upon the magnetic needles. By connecting the first binding screw on the base with the third, and the second with the fourth, the coils will be coupled up so as to reduce the resistance to one-fourth of the total resistance of all the coils together. Over the coils a glass shade is placed, from the middle of the top of which a brass rod rises. A short piece of brass tube slides over this rod with a weak steel magnet, slightly curved, fixed at right angles to it. This magnet can be slid up and down the rod, or twisted round for adjustment of the mirror. For fine adjustments a tangent screw is provided, which turns the brass rod round, and with it the magnet.

1128.



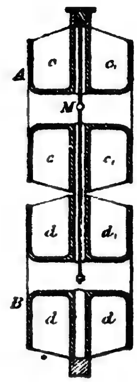
The mirror is sometimes made of a plano-convex lens, to obtain a sharp image of the spot of light on the scale. The width of this spot of light can be regulated, by means of a brass slider fixed over the hole in the screen through which the beam emerges from the lamp. A much better arrangement than the spot of light is to make the hole through which the light emerges round, with a piece of fine platinum wire stretched vertically across its diameter. A lens is placed a little distance in front of this hole, between the scale and the galvanometer, so that a round spot of light with a thin black line across it is reflected on the scale. This enables readings to be made with great ease, as the figures on the scale can be more distinctly seen. The mirror in this arrangement may be a plane one. When the spot of light only is used, it is necessary to partly illuminate the scale with a second lamp.

Fig. 1129 is a sectional view of the coils, showing the mirror M and the lower needle N, removed in Fig. 1130. When these instruments are used for receiving communications through cables, they are placed in a box or curtained compartment, and the receiver calls off each word to a clerk, in attendance, who writes it down. The spot of light wanders over the scale, following every change of current, but the operators, by practice acquire the necessary skill to interpret the apparently irregular motions. One dot will cause the light to almost cross the scale, the second moves

it a little further, the third or fourth causes hardly a perceptible motion, but the receiver knows by experience that these four very different effects each indicate a series of dots, all sent by the transmitting operator in precisely the same manner.

Thomson's marine galvanometer is a reflecting galvanometer, constructed in such a manner that the oscillations of the vessel cannot change the relative position of the small mirror and the scale, when used on board cable ships, and for other similar purposes.

1129. 1130.



The magnet is attached by means of cocoon fibres, at the top as well as at the bottom, to small wooden frames, which support the convolutions of wire. The cocoon fibres pass accurately through the joint centre of gravity, both of the magnetic bar and the mirror, so that, when the wire of the coil is turned, the latter remains unaltered in its relative position to the convolutions. The magnet thus retains, in any position of the instrument, the same position in relation to the scale attached to it on the same table.

This instrument has the influence of terrestial magnetism upon the magnet destroyed. This is attained by enclosing the multiplicator wire with magnet mirror and lens in a case of soft iron, and by putting in the box a moderately strong steel magnet. The magnetic action of these poles upon the magnet needle being stronger than the attractive power of the earth, the latter is neutralized, and the suspended needle is maintained in a position of rest under the changes of the situation of the instrument.

To avoid the disturbing movements of the spot of light upon the screen, caused by the shaking and flickering of the flame, the lamp is enclosed in a cylindrical case, in which, on the side turned towards the mirror, is a small slit. When the galvanometer needle is at rest, the spot of light appears exactly upon the middle of the screen.

Electrometers are made in different forms, some of which are historical. They all depend, for measurement of the intensity of the electrical potential, upon the repulsion or attraction of a light body by a fixed body, both being electrified. Practically only one electrometer is in use, and it is known as the reflecting quadrant electrometer invented by W. Thomson. This instrument consists of a metallic box, cut into four quarters or quadrants, which are slightly separated, and well insulated from each other. Within the box is suspended a flat needle, the extremities of which are broader than the middle. This needle has a bifilar suspension and communicates electrically with a Leyden jar. The Leyden jar is maintained at a constant electrical potential, by means of a small charging apparatus attached to the instrument, and by placing the jar in an atmosphere deprived of moisture, by contact with highly concentrated sulphuric acid. Each two diagonally opposite corners of the box, within which the needle swings, are connected electrically, so that the needle, when each set of quadrants is electrified to the same potential, has no tendency to deflect from the position given to it by the bifilar suspension. When one set of the quadrants is electrified to a lower or a higher potential than the other, or when each set is oppositely electrified, the needle will be so deflected, as to be attracted by the lower or opposite potential or repelled by the higher or similar potential. The deflection is proportional to the difference of potentials, when indicated by a beam of light reflected from a mirror on the axis, of the needle, to a scale, as in the reflecting galvanometer.

Electrometer observations are attended with considerable difficulty, consequent upon the liability of the state of the atmosphere to influence the instrument, and because accidentally touching certain parts in connection with the Leyden jar may cause its discharge, when all previous observations must be repeated. The instrument is besides not portable, and cannot, like the galvanometer, be easily set up; it is, therefore, very usual in practice, to substitute a combination of condenser and galvanometer for the electrometer.

In the Thomson quadrant electrometer an inverted bell glass is externally coated with tin-foil, which is put in communication with the earth. In the interior of the jar is concentrated sulphuric acid, into which dips a platinum wire attached to the needle, suspended in the quadrantal box. The quadrants are supported from an ebonite disc, and are adjustable with regard to each other, so that the needle may be brought to the zero of the scale. Measurements with the electrometer are chiefly made in the factory with short lengths of indiarubber or Hooper's cores. Beyond this application to the measurement of insulation by loss of charge, the instrument does not meet with much favour in the testing room.

Condensers are usually prepared with sheets of tin-foil separated by sheets of mica, or of paraffined paper. Mica is used for small, and paraffined paper for large condensers. Mica condensers are more durable, but the capacity varies with sudden alteration of temperature, consequent upon the separation or approximation of the tin-foil sheets.

In the construction of the condenser, there is first laid upon a metal surface-plate, a sheet of tin-foil, the commencement of the earth armature. Upon this is laid a sheet of insulating material, mica, or paraffined paper, of much larger area than the sheet of tin-foil, but having one of its corners removed so as to expose the tin-foil; upon this sheet of insulating material is laid another sheet of tin-foil, which is the commencement of the line armature. This is followed by another sheet of paper, so cut at the opposite corner to the first sheet, as to similarly leave a portion of the tin-foil exposed. A sheet of tin-foil is now superposed so that it is in contact at the cut corner of the paper with the sheet first laid down, and forms the second sheet of the earth armature. By continuing the operation the construction of the condenser is completed, when as many sheets have been laid down as are necessary to give the required capacity. About 10 sq. ft. of tin-foil surface, or 5 sq. ft. in each armature, is necessary for a condenser of one microfarad capacity; but the capacity depends upon the proximity of the plates, and may be slightly greater by subjecting the

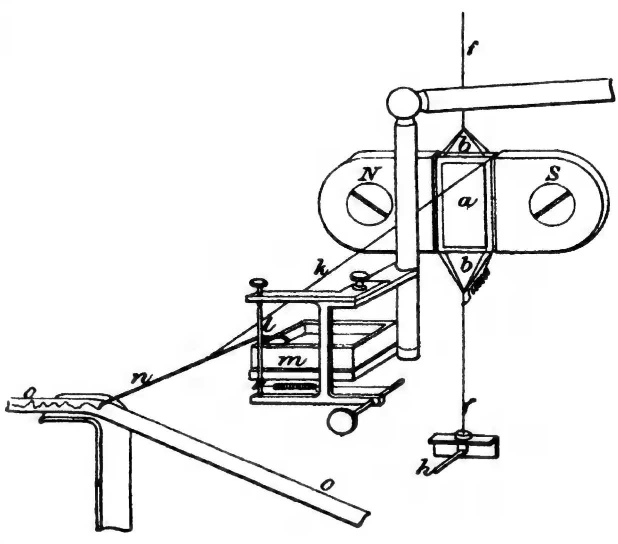
condenser to pressure during manufacture. When completed the condenser is usually placed in a warm atmosphere upon a heated surface-plate, and is loaded with about 8 cwt. When the condenser is sufficiently warmed through, the source of heat is removed, and the sheets are allowed to cool in their compressed condition. The condenser is finally surrounded with solid paraffin in a box.

The paraffin to be used in the making of condensers should not be heated in a brass or copper vessel, as if it absorbs verdigris it becomes conducting. Where condensers are to be used in very hot climates 2, or 3 per cent. of Carnauba wax is added with advantage to the paraffin. For the manufacture of paper condensers, paper containing mineral substances is useless, and the best variety appears to be that known as cream-wove bank post from linen rags. Mica for use in condensers must be clear and free from fracture; black mica is not suitable for the purpose. Condensers should always be left with their armatures connected electrically, so that they may be completely discharged when required for use.

The siphon recorder invented by W. Thomson is so arranged as to actually delineate on paper the apparently irregular movements of the galvanometer needle. A fine glass siphon tube conducts the ink from a reservoir to a strip of paper, which is drawn past the point of the the tube with a uniform motion. The point moves to the right or left of the zero line, through distances proportional at each instant to the strength of the current, and thus the signals are drawn on the paper in curves.

Fig. 1131 shows the form of siphon recorder in use at the Duxbury Station of the French Atlantic cable. The apparatus consists of a very light rectangular coil *b b* of exceedingly fine insulated wire, suspended between the poles of a large and powerful electro-magnet N S, which is charged by a local battery of large size. Within the coil is a stationary soft-iron core *a*, which is powerfully magnetized by induction from the poles N S. The coil *b b* swings upon a vertical axis, consisting of a fine wire *f f* the tension of which is adjustable at *h*. The received current passes through the suspended coil, the suspension wire *f f* serving as the conductor; the coil is impelled across the magnetic field in one direction or the other, according to the polarity and strength of the current passing through it. The magnetic field in this arrangement is very intense and very uniform, which makes the apparatus sensitive to the weakest currents. The siphon *n* consists of a fine glass tube turning upon a vertical axis *l*; the shorter end is immersed in the ink reservoir *m*, and the longer end rests upon the paper strip *o o*. The siphon *n* is pulled backward and forward, in one direction, by the thread *k*, which is attached to the swinging coil *b b*, and in the other, by means of a retracting spring attached to an arm on the axis *l*, and controlled by an adjusting spindle. The paper is caused to move at a uniform rate by means of gearing driven by a small electro-motor.

1131.



S I P H O N R E C O R D

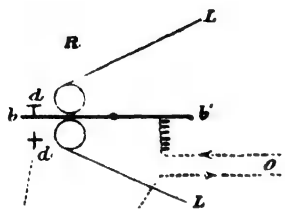
Fig. 1132 is a fac-simile of the writing of the siphon recorder at a speed of eighteen to twenty words a minute, through a cable of about 800 miles in length. The upward waves represent dots, and the downward waves dashes. In working very long cables, the action of the current upon the swinging coils is very feeble, and the friction of the siphon against the paper strip, if allowed to come in actual contact with it, would interfere with the freedom of its movements. In such cases the point of the siphon does not actually touch the paper; the ink and the paper are oppositely electrified, by means of an inductive machine driven by the electro-motor that moves the paper. The electrical attraction causes the ink to be ejected from the siphon upon the paper in a succession of fine dots.

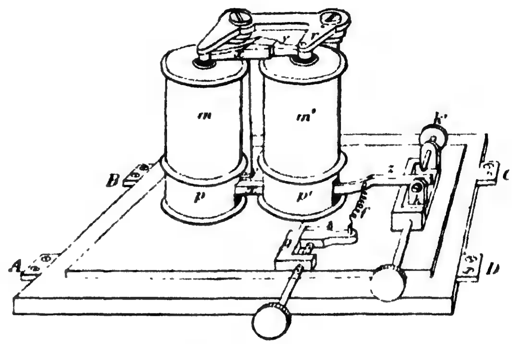
In introducing the relay into diagrams of apparatus, it is often represented in the conventional manner shown in Fig. 1133, in which *b b'* is the armature lever, *d* the insulated or resting contact, and *d'* the closing or working contact. L L represents the main circuit, and the dotted lines O the local circuit.

Various other forms of relays have been introduced. A relay designed by Siemens and Halske, with a movable core, but without an armature, Fig. 1134, has been much used. The helices *m m'* are electrically connected in the usual manner, A and B being the main binding screws. One of the cores *x* is stationary, the other one *y* turns upon screw points *r*; both of these cores are

provided with pole pieces, which face each other. The contact arm *z* is rigidly attached to the movable core *y*, and serves to open and close the local circuit at the contact screws *k k'*. the former being insulated. The adjusting screw *g* regulates the tension of the relay spring *f*. C and D are the local connections.

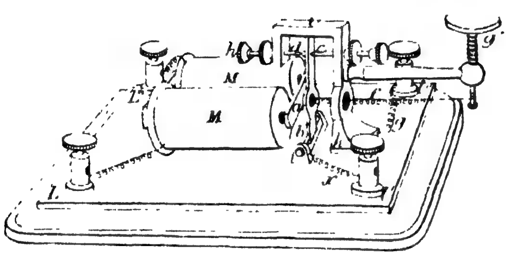
The form, Fig. 1135, is known as the American relay, and is the simplest in principle, being an armature *b* held back by a spring *f*, and attracted by the magnetism generated by the passage of

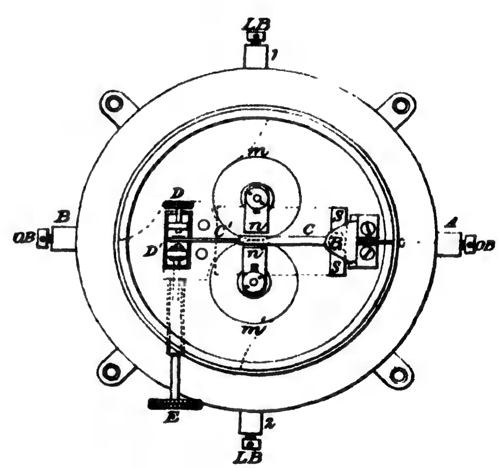




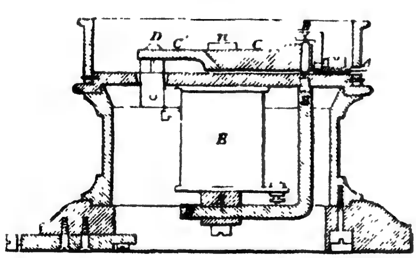
the currents in the coils M, of the electro-magnet; *d* is the working, and *c* the rest stop; *g* is an adjusting screw; L' and L'' are the line; and *l'* and *l''* the local connections.

Siemens' polarized relay is in general use, and is regarded as an improvement on the ordinary Morse relay, particularly as it does not require any adjustable spring as a retractile force. Fig. 1136 is a plan view of this instrument, and Fig. 1137 the vertical section through the centre. The relay consists of a steel magnet N S, bent to a right angle, on whose leg N the soft iron





1137.



cores *n n'*, and the wire coils or helices *m m'*, of an electro-magnet are fixed. At the extreme end of the other leg S is a small soft-iron bar *c c'*, which operates as a relay lever and armature, turning horizontally on its pivot B. The motion of this armature is limited by the metallic screw D on the one side, and by the agate stud D' on the other. On the leg of this magnet the iron coils *n n'* are attached, upon which the coils *m m'* are wound. The south pole S polarizes the tongue *c c'*.

Soft iron, when placed in contact with the pole of a magnet, becomes itself magnetized, and takes the same polarity as the pole with which it is connected, so that the upper ends *n n'* of the iron core, standing on the north pole *n*, form permanent north poles, and for the same reason the extreme end *c'* of the armature *c c'*, which at S stands on a south pole, is permanently a south pole. Therefore, the armature will be attracted equally by north pole *n* and *n'*, but if it be brought nearer to one than the other it will be held there. If the attraction between *n'* and *c'* predominates, the armature lever will lie against the point D, and if the attraction is greater between *n'* and *c'* it will rest on the agate point D'. It is evident that the latter position, where the local battery, which is put in between D and B, is open, corresponds with the position of rest of the ordinary relay.

When the key is closed at the remote station, and a line current is sent through the coils $m\,m'$, one of the poles, $n\,n'$, becomes oppositely polarized. Suppose that this current causes at n, a north pole, and at n', a south pole, then the north magnetism already at n is increased, but destroyed at n'.

As the south magnetism at c is, however, unchanged, the attraction of n towards c' is predominant, and the tongue of the lever, $c\,c'$, strikes against the contact screw D, and closes the local circuit.

When the line current ceases the lever still remains in contact with screw D, as although the electro-magnetism from $m\,m'$ disappears, the attraction between c and n continues predominant, on account of c' being nearer to n.

The return of the armature, $c\,c'$, to its former position can only be effected by a reverse current, which is produced at the remote station by a pole-changing key, the south magnetism being induced at m, and north magnetism at m', by which the north magnetism already to be found at n is decreased and strengthened at n', consequently the former attraction between n and c' is destroyed, and the attraction between n' and c' predominates. The tongue $c\,c'$ thus again strikes against the insulating point D′ and interrupts the local circuit, whose poles are connected with A and B.

No adjustment of the armature lever is required after it has been properly placed by means of the regulating screw E, no matter which pole of the battery is to line, and thus the use of a spring as a retractile force is entirely dispensed with.

The polarized relay can be very advantageously used for ordinary battery currents of one direction. For this purpose it is only required that the movable pole pieces $n\,n'$, shall be placed at different distances from the polarized tongues $c\,c'$. The piece, n', which corresponds to the rest or D′ side, must be placed nearer to the tongue $c\,c'$ than the piece n. In this case, as long as no current passes through $m\,m'$, the attraction to the north pole, n', of the south polarized tongue c' increases; consequently the armature c' is constantly attracted by n', and remains against the insulated point D′ interrupting the local circuit. When, however, a line current arrives of such a polarity as to form at m a north pole, and at m' a south pole, then the north magnetism already present at n is increased, and the south magnetism present at n' destroyed or replaced by south magnetism, so that the attraction of n and c' predominates, and accordingly the tongue $c\,c'$ is drawn over to the opposite side, and closes the local circuit at D. With the breaking of the line current the magnetism at m and m' again ceases, but the north magnetism at $n\,n'$, caused by the steel magnet N S, remains, and consequently the tongue at n should remain in the same position; but as the space for motion between D and D′ is very small, only a slight change is made in the distance of the tongue from n and n', on account of its movement towards n, and it has thus, as before, on account of its position, more attraction for n' than for n. As c' stands nearer to n' than to n, the attraction of n' predominates, and the tongue is pulled back, interrupting the local circuit until another line current closes it.

The polarized relay is exceedingly sensitive on account of the absence of the retracting spring, the force of which the electro-magnet is not obliged to overcome, and also because the action of the poles n and n', on the armature $c\,c'$ is a double one, attracting and repelling at the same time. No adjustment is required to meet the varying strengths of the line current. To adjust the polarized relay, the pole pieces n and n' are placed at a convenient distance apart, and the screw B turned until the tongue is brought as nearly as possible in the centre between the poles, so as to have equal room for adjustment on each side. The set screw, D, is adjusted so that the motion of the tongue or armature lever, shall be about one-twentieth of an inch between the insulated stud D and the contact point. The adjusting screw E, is then turned, so that the armature, when no current is flowing, shall be slightly attracted by the pole n', bringing the tongue into contact with the agate point D′. If, after the instrument is so adjusted, the armature lever remains permanently in contact with the circuit closing point, D, when the distant station is sending, the screw E is turned to the right, so as to lessen the attraction of n and increase that of n'. If this produces no effect, either n is placed farther from, or n' nearer to the tongue, until the desired result is obtained.

Allen and Brown's relay, Fig. 1138, consists of an electro-magnet A, of proper form and dimensions, suspended between permanent magnets, and free to move, when excited, to right or left, as far as the compensating springs which are attached to one end of its core will allow. These springs will only permit the electro-magnet to move to a point where the potential of the current and the tension of the springs balance each other; and the electro-magnet will truthfully follow the pulsations of the received current in a natural manner.

A contact arm is loosely pivoted on the top of this moving coil, and is termed a jockey armature, which, being light, and favourably placed, opposes only the friction caused by its weight to the free movement of the coil. A local circuit made through this jockey would be closed the moment the coil moved, and would remain closed as long as it continued to move in the same direction, but immediately a fall of potential took place, and the coil, through the action of the springs receded, however slightly, the local circuit would be broken.

It is possible, with this relay, to obtain arbitrary characters, such as the Morse, on a rise or fall of potential, without bringing the cable current to zero. The weight of the "jockey" gives sufficient friction for contact purposes, the spiral spring of the centre pivot being seldom used. An increase of friction means so much more opposition to the free movement of the coil, and is detrimental proportionately. The local contact points, on each side of the jockey, may be either or both used, if a reverse current in the local circuit be desirable.

The local contact points must be adjusted so closely, that no motion of the jockey is visible; sufficient only to make or break the local circuit being necessary. The compensating springs should be adjusted rather stiffly so as to ensure the greatest amount of elasticity.

The electro-magnet of whatever local instrument is used in direct communication with the

cable relay, may be shunted with a condenser of, say, 10 microfarads, to avoid the spark at the point of contact on the jockey. The success of this relay is due to the fact that it affords what is termed a moving zero. Relays generally in use have fixed or dead zeros.

Instruments cannot be worked with reasonable speed through cables over 300 miles which do not afford this quality of a moving zero, and the success of the Thomson mirror and recorder, and

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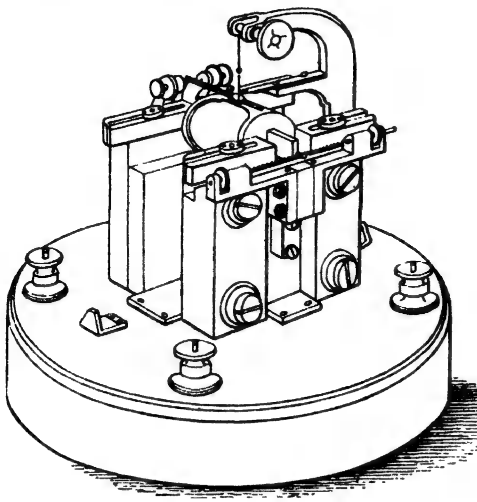

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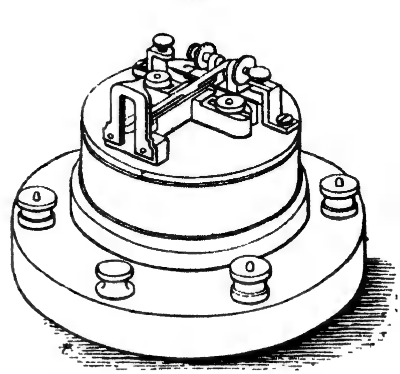

the Allan and Brown relay, is due to their containing this element. On cables of 300 or 400 miles this jockey armature can be attached advantageously to any existing instrument, such as a Siemens or other relay, Fig 1139, and the speed increased.

Wheatstone's automatic apparatus, introduced in 1858, is considered by electricians to be the most perfect form of automatic telegraph brought into practical use. The apparatus includes a perforated strip passed through a transmitter, with a polarized receiving instrument. In earlier automatic telegraphs, contact was made directly through the perforation of the paper, by passing the paper between a metallic brush and a wheel; but in this construction dust or fibres of the paper interfere with the contacts, and the edges of the perforation act upon the brush, to prevent it from touching the metal wheel, for a considerable portion of the space allowed for contact. Attempts were made to obtain better results by lengthening the perforations of the paper, and by running the machine faster. In Wheatstone's transmitter the contacts are made between levers and studs, the paper being used only to regulate the movements of this contact piece. This plan gives much more uniform and certain contact than can be obtained between the brush or spring, and the revolving wheel, besides affording great facility for transmitting the compensating currents required at high speeds.

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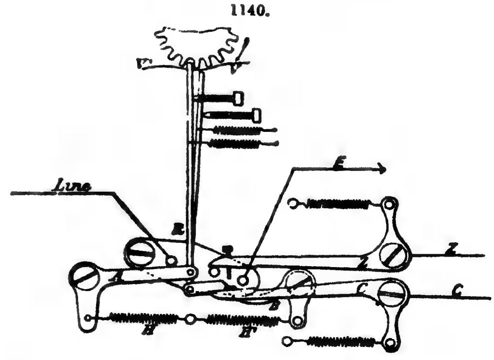

The principle in Wheatstone's apparatus is that the polarized arm of the electro-magnet, which causes the marking disc to touch the paper, shall not have a tendency to leave the paper when the marking current ceases, but to remain always in the position where left by the last current. The transmitter is arranged to send a series of reversals, or limited positive and negative currents, at regular intervals, and the perforated strip controls these currents of either sign in their passage to line. An ebonite rocking beam R, Fig. 1140, actuated by clockwork, carries three pins; that on the left being connected to line, and that on the right to earth. The centre pin is insulated, and can connect the curved lever B with one or other of the battery levers Z C, controlled by the position of the rocking beam. Beneath the beam are two levers, A B, pivoted independently, but in electrical connection through the spiral springs H H', and through the frame of the instrument. These levers carry two vertical needles, one of which, V, regulates the marking, the other, V', the spacing current. The levers follow the movements of the rocking beam, and remain in contact with the pins in this beam so long as the upward movement is unchecked; the needles attached to this lever rise alternately until they touch the paper ribbon. If there is a hole in the ribbon, the needle passes through, and the contact remains unbroken; if the paper is unbroken the motion of the needle and that of the lever is stopped, and the pin in the rocking beam continues to rise,

and the circuit is interrupted. Fig. 1140 is of the apparatus in a position for sending a negative current; the lower lever, C, touches the right-hand pin on the rocking beam, putting the copper pole to earth; the upper lever, Z, rests on the centre pin of the beam, and is in connection with the line over the lever B, the spiral springs, H H′, in the frame of the instrument, the lever A, and the left-hand pin. When the circuit is broken, the rising of the lever A is prevented by the paper, the vertical needle, V′, attached to it not meeting with a hole in the strip. The contact between the lever A and the left-hand pin is broken, and there is no current passing to line.

From well-known inductive effects on the line, no more than 70 words a minute are attainable by automatic telegraphs, based on the Bain's principle of brush contact. By the use of alternating currents speed is increased, but is still considerably lower than the maximum attainable on a given line. The succession of currents of equal duration of opposite signs, at equal intervals, will give perfectly distinct dots, at very much higher speed than the dots of alphabets can be produced. Wheatstone's transmitter produces the Morse signs by currents of equal duration, that is by a succession of dots, but as the intervals between the characters are necessarily unequal, the alphabet is more slowly produced than a series of equidistant dots. The speed of a succession of alphabet letters depends also on the distance between the letters; the greater the distance the slower the speed, because an additional element of variation in the electrical condition of the wire and the magnetism of the receiver is introduced. Speed is generally limited more by defects in the formation of the letters than by the complete loss of dots or blurring of marks, and the defects are greatest where there is the most irregularity in the intervals between currents, as, for instance, in the letters F and R in the Morse code, the Morse signals for which are — — —— —, — —— —.

It is necessary, therefore, to employ a system of compensating currents, to maintain uniformity in the condition of the line wire. This was effected at first by bridging over the break in the circuit, which occurs when the pin is stopped by the paper, by a weak current passed through resistance coils, the strength of the current being regulated by varying the resistance.

Fig. 1141 is of a piece of the perforated strip. The perforations which regulate the contact-making portions of the transmitting apparatus are represented by the larger holes, while the centre row of holes serves for guiding the paper through the transmitter. The slip is perforated for transmitting the letter R; the upper row of holes is that which allows the positive or marking current to be sent, when the vertical pin, V, of the transmitter, passes through one of them; the lower row of holes allows the negative current to be sent when the vertical pin, V′, passes. Fig. 1142, is of the letter R as received at high speed, on a line where the original system of intermittent currents is employed. In the case of the dot before the dash, the positive, then the negative, and finally a second positive, giving two positive and one negative currents, are sent to form the dot and commence the dash, so that twice as much positive as negative electricity is sent into the line, and the dot is consequently much elongated, and has a tendency to blur into the dash. In the case in which the dot follows the dash, the effect is reversed, the space increased, and the dot shortened or lost. Fig. 1143 is of the letter R as received when compensating currents are used, and is perfect in form. The compensating currents are represented by the smaller signs. Before the commencement of the dot the line is charged negatively, instead of being clear, as in the original system, and prevents the elongation of the dot before the dash. In the case of the dot following the dash, the positive compensating current is sent before the terminating current for the dash, so that the line is not too highly charged with negative current, as would be the case were no compensating current used.

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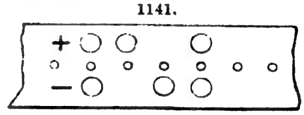

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This instrument has given some very instructive results in the working of compound lines, part of which are of cable and part of overhead wires. It has been found that in circuits partly of overground wires, and partly of buried or submarine wires, that the position of the buried wire will affect the speed at which the two stations can receive from each other. If the buried portion is placed symmetrically with respect to the two stations, as when the land lines at each end of the cable are of equal length and resistance, the two stations will be able to receive equally well, but if the land lines on one side are much longer than the other, the rate at which the station situated at the end of the shorter land line will be able to receive, will be less than that at which the station situated at the end of the longer line can receive from the other. This difference of speed is sometimes very considerable, and the difference is greater as the length and resistance of the land lines on each side of the cable are more unequal. The London and Amsterdam circuit consists of a suspended wire of 130 miles, then a cable of 120 miles connected to a suspended wire of 20 miles. Amsterdam can signal to London at a rate higher than signals can be sent in the opposite direction, as nine to six. The rate of signalling to Amsterdam is increased by decreasing the resistance of the batteries, and by the insertion of a high resistance, as much as 5000 ohms, at Amsterdam, in the receiving circuit, to delay the discharge of the cable. In the case of the London-Dublin circuit, where the land lines are 266 and 10 miles respectively, and the cable 66, the addition of resistance at Dublin in the receiving circuit has no appreciable effect, because the length of land line on the English side is too great to permit the cable to be sufficiently charged. Here the speeds are 40 and 80 respectively. With Wheatstone's automatic telegraph the speed between London and Manchester or Liverpool is 120 words a minute, in some cases as many as four intermediate stations are introduced in the circuits devoted to press work, in which 1000 words are sent simultaneously to each station in twenty minutes, with regularity.

The arrangement of circuit, Fig. 1144, is that in use in America, for automatic telegraphing on long circuits. A is the transmitting, and B the receiving station. At the transmitting station two equal batteries, E and E_1, are placed in the main circuit, with their like poles towards each other, and normally produce no effect on the line. When, however, the battery E_1 is shunted by the

by r; so that if the latter makes another revolution whilst the finger is kept down upon the key, no second contact is made, and the same letter is not repeated. The operator feels a vibration of the key as the shovel passes by the pin, and is thus made aware that the letter has been printed.

The type wheel H contains on its circumference, in twenty-eight equal spaces, twenty-six letters of the alphabet, a dot, and a blank space; it is fixed to the extremity of the axis CC′, which is put in motion by means of the hollow axis, G, enveloping it in the greater part of its length. The connection between CC′ and G is made by the mediation of a fine ratchet wheel G_5, attached to the axis G, the click m being on the axis CC′. On the latter are supported, besides the type wheel and click, a corrector H′, or wheel with long narrow teeth, equal in number to the types, serving to establish precision between the movements of the horizontal arm r, and the type wheel. On the same axis is a wheel H_1, having a notch at one part of its circumference, for stopping the type wheel when the blank space is opposite the printing press, in case it should spring forward. The hollow axis G is turned

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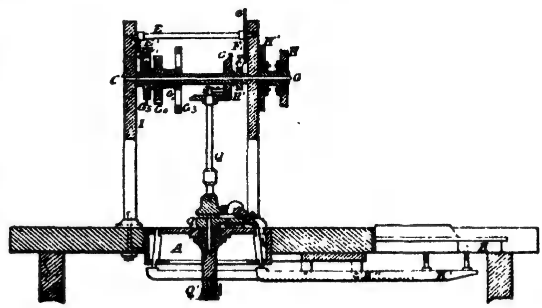

by a clockwork moved by a weight, a wheel of which engages with the pinion G_1, and supports, besides the wheels G_5, G_2, the escape wheel G_4, and a tooth-wheel G_3, which locks into the pinion I_1 of the printing shaft I, shown in section in Fig. 1149.

The printing shaft turns seven times as fast as the type wheel, and carries a fly-wheel I″ at one extremity, in order to overcome the inertia of a small shaft, whose duty is to lift the paper up to the type wheel at the other extremity. The printing shaft I, and its continuation i, are locked together by means of a ratchet wheel I, and click i''. At the end of the continuation shaft i, is a cam h, for lifting the press and the paper against the type wheel.

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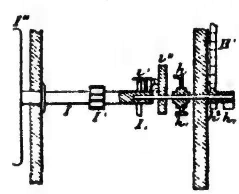


In the printing press underneath the type wheel is a small cylinder, over which the paper is led, its axis being in the middle of a bent lever; attached to it is a ratchet wheel, in the teeth of which catches a click affixed to a movable piece, terminating in a rectangular arm, which is forced upwards by a spring attached to the frame of the apparatus, but is stopped against the axis. When this makes one revolution, the cam lifts the arm of the lever, together with the cylinder and paper strip, up to the lowest tooth of the type wheel, by which the paper strip is impressed with the print of the type, kept inked by an inking roller. The cam being very sharp, the movements of ascent and descent are proportionately rapid, and the paper touches the type during only an infinitely short space of time. The axis continuing to turn, the cam meets the arm, and depresses it, causing the click to draw round the cylinder and advance the paper a certain distance.

By the side of the ratchet wheel the printing shaft carries an escapement h h', arrested by a continuation of the lever moving with the armature of the electro-magnet. The armature is of soft iron, supported at the extremity of a lever over the poles of an electro-magnet. The lever turns between supports on the axis, and tends to rise by the force of a spring regulated by an adjusting screw. When a current traverses the coils of the electro-magnet, the armature and lever are depressed, the click is put in gear, and the pallet of the escapement, released, turns with the axis. At the moment when the pallet passes under the lever, it relifts it, and depresses a screw, returning thereby the armature to the poles of the electro-magnet, and, at the same time, throwing the click out of gear.

The magnet employed consists of a permanent horseshoe magnet, with soft-iron cylindrical continuations on the poles. These continuations are each encircled by a coil of wire. When no current passes through the coils, the armature is attracted to the poles by the magnetism distributed in the iron. This force is opposed by the adjusting spring, which is so regulated that, the armature being in contact, a very weak current is able to neutralize the attraction.

The printing shaft has also the duty of correcting the movements of the type wheel, and of ensuring always that, at the moment of printing a letter, the type is in its proper position. This is effected by means of a curved cam h_2, on the axis i, Fig. 1149. The instant the cam h' lifts the arm of the frame carrying the printing roller, the projection h_2 locks into the teeth of the wheel H, and adjusts, if it be necessary, its position. If, on entering the teeth H, the cam has to push the wheel forwards, or to accelerate the motion of the axis C C, the click m is pushed onwards, passing over one or more of the teeth of the ratchet wheel G_5, Fig. 1148.

If, on the contrary, the cam has to retard the motion, the click pulls the ratchet wheel backwards, for which purpose the latter is not made rigid on the axis, but is formed of a disc held between leather washers supported by two plates of metal, fixed on the hollow shaft G.

The electric circuits of the apparatus are very simple. The bottom of the vertical shaft, Q, is connected to earth, and the upper part to one end of the coils of the electro-magnet, the other end being to line. One pole of a battery is connected to the levers k of the contact pins, the other pole to earth. At two corresponding stations the plates of the batteries must always be looking the same way, because the home apparatus is intended always to work as well as that of the distant stations, and the armature of its magnet is only liberated by currents in one direction.

When a current arrives, therefore, from the line, it passes first through the coils of the magnet, then through the vertical shaft Q, which it descends, and goes over from the screw in the jointed arm to the resting-piece, and from this to earth. When a current is to be transmitted, the operation consists principally in interrupting the earth circuit, and in inserting the battery into the break. This is done by the contact pins and jointed arm of *r*. A key being depressed, the arm *r* in its journey rides over the pin, and its screw is lifted up from contact with *r′*, which breaks the direct earth circuit. At the same time the contact of *r′* with the pin *k*, which is in communication with a pole of the battery through the lever K, sends a current from the battery through the coils of the magnet into the lime.

Suppose two such apparatus properly adjusted at the extremities of a line of telegraph, the clockwork wound up, the electrical connections duly established, and the type wheels locked. The employé who desires to transmit presses down the blank key of his instrument; this pushes up the corresponding contact peg in the circle, and when the chariot arrives over the pin, the extremity of the piece rides over it, separating the earth contact, and introducing the battery into the line circuit. The current passes through the vertical shaft, the coils of the magnet, and line wire to the other station, where it circulates in the coils of the magnet, the vertical shaft, and goes to earth.

In traversing the coils of the magnets of both instruments, the current weakens the attractions of the armatures to the poles of the electro-magnets; the former are forced off by the spring, the screws are raised, and the levers at the same time depressed. The pallets, *h*, of the escapements, *h h*, are thereupon released, the axes, *i*, put into gear with I, and the type wheels released. During the revolution made by the axes *i*, the cylinders are raised by the cams, and lift the paper up to the printing wheels, at the moment when the latter are unlocked. No letter is printed, because the blank space in the type wheel occurs just there. The paper strips and cylinders descend again, the former advancing a step. The clicks are then disengaged from the ratchets, and the pallets, *h*, recaught by the levers, which were lifted up, causing the armatures to be pushed down again to the poles of the magnets.

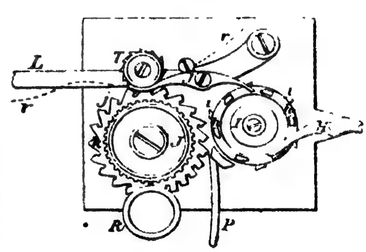
If a key answering to any letter be now pressed down, the current is repeated the moment the chariot passes over the raised contact pin; the printing axis is put in motion, the letter printed, and the paper pushed on as before, and so on, until the message is completed.

It sometimes happens that the apparatus do not agree when one of the stations sends its message. In this case the employé at the receiving station advises his correspondent of it by giving him a signal; both then arrest their type wheels, and the transmission is recommenced, beginning always with the blank.

To avoid the inconvenience of irregular working which might arise from changes in the battery power, Hughes has adopted a method of short-circuiting the coils of the electro-magnet, the instant after the armature is released, so that the current, whatever may be its intensity, comes into play only long enough to effect the required weakening of the magnetic attraction.

Hughes' type printer has been considerably modified in America, with the object of rendering it less complicated and increasing the speed at which the type wheel can be made to revolve without injury to the parts. Fig. 1150 is a plan of the printing mechanism attached to this modified instrument. The printing wheel I is carried on the main shaft of the instrument, which receives its motion from a transmitting cylinder; upon its upper surface are fixed six angular pins *h h*; a detent on the end of the escape lever H takes hold of one of these pins, whenever the circuit of the electro-magnet is broken, but instantly releases it when the circuit is closed. The effect of each electrical pulsation sent through the electro-magnet of the receiving instrument is, therefore, to release one of the pins *h*, allowing the printing wheel I to perform one-sixth of a revolution, when it is again arrested by the detent of the escapement lever catching the next pin. Meanwhile the type wheel J is constantly revolving, so that the wheels I and J of the receiving instrument, and the transmitting cylinder of the sending instrument, perform the same number of revolutions in the same time. J has twenty-eight characters upon its circumference, and underneath these are two circles of teeth *j* and *k*, equal in number to the characters upon the type wheel.

1150.



In operation, when the printing wheel I is released by the action of the electro-magnet, it performs, as before stated, one-sixth of a revolution. Two distinct operations are effected by this movement, first one of the teeth *i i* enters between two of the teeth *j* of the type wheel, and effects any necessary correction of the error in its position, by moving it a little forward or backward upon its axis; secondly, one of the pins *h* press back the tail of the lever *j*, and this brings the paper strip *r*, which is carried by the cylindrical platen T into contact with the type. A circle of teeth upon T gear, with corresponding teeth *k* on the type wheel, and the two revolve together as long as the contact lasts between the paper and the type, so that the feeding of the paper is accomplished while the impression is taking place. The types are inked by a felt roller R. The unison stop P is employed by the receiving operator to arrest the type wheel at zero or dash, when starting. It is thrown off the type wheel, and released at the first movement by one of the pins *h h* striking against the projection on the upper surface of the lever. The bar L supports the platen and its attachment; it is pushed back, so as to throw the impression lever out of gear with the printing wheel, when sending.

Phelps' electro-motor printing telegraph, largely used by the Western Union Telegraph Co., U.S., has the type wheel and printing mechanism operated by a local battery. This construction enables the working parts to be made much stronger than in the Hughes instrument, where the moving

parts must necessarily be light. These parts consist of a transmitter with keyboard for closing the circuit, the receiver or printing mechanism, containing apparatus for maintaining unison automatically, the electro-motor, and the governor for speed. The transmitting apparatus and the type wheel of the receiving instrument are caused to revolve synchronously, under control of the governor, and each letter is printed by a single pulsation of the electric current, of determined and uniform length, transmitted at a given time. The motion of the type wheel is arrested while each letter is being printed, and is automatically released, the instant the impression has been effected. By this means a greater speed of revolution is given to the type wheel than it would be possible to attain by a step by step movement, and also letters which happen to come in direct sequence upon the keyboard, may be printed from, during the same revolution. The instrument is secured upon a base 18 in. by 23 in., and the keyboard consists of twenty-eight keys, together with a period and space. Directly in rear of the keyboard is a hollow column A, Fig. 1151 which contains a circular range of twenty-eight vertical slide rods, corresponding to the keys, and the mechanism by which the circuit closer is actuated. The vertical slide rods a are connected with the keys, as in Hughes' printer, and are provided with angular heads a^1, projecting towards the centre of the hollow column; their inner ends rest in slots formed in a guide ring a_3, projecting from the upper surface of the guide plate A^1. The inner ends of these heads form a compact circle of about $1\frac{1}{2}$ in. diameter. The pulsations of the current are transmitted upon the depression of the keys as follows;—In the centre of the hollow column A is a vertical shaft C, revolving continuously at 241 revolutions a minute, being driven by the wheel E, receiving its motion from the electro-motor. The speed of this shaft is controlled by a governor, and upon the shaft is a hollow flanged collar B, fitted loosely. When none of the keys are depressed, the collar B revolves with the shaft C, and the wheel E being coupled to them by a catch, pressed by a spring into one of four shallow vertical grooves cut in the outer periphery of the collar. A pawl is pivoted to the flange of the collar, and revolves almost in contact with the circle of twenty-eight ratchet teeth d, formed on the inner edge of a stationary annular plate D; the arm of the pawl extends through an opening into the interior of the drum, where it rests against a roller mounted upon a spring. The bottom of the collar B is formed into a flange, the under surface of which consists of two inclines, one of these inclines being short and sudden, and the other being gradual and in the reverse direction extending round the remaining portion of the circle. The flange revolves immediately above the inner ends of the angular heads of the slide rods. Upon the top of the collar are four projections with bevelled corners, each occupying one-eighth of its circumference. The horizontal pusher e mounted upon a spindle within the hollow wheel E, carries the short bevelled arm, extending downwards, and along the side of one of the projections e_1. The foot of a slender vertical rod c, rests upon this lever and extends upwards, through the hollow parts e of the shaft C, to the screw g. This rod c when pushed upwards serves to actuate the circuit closer. When one of the keys is depressed the corresponding slide is raised, and its angular head is pressed against the under surface of the flange b upon the collar B, which together with the shaft C is revolving at the rate of four revolutions a second. When the incline of B passes over the elevated slide head, the sharp head of the pawl is struck by it. In consequence of its inclined form the pawl is forced outward, and into contact with the opposite ratchet tooth d in the plate D, by which the rotation of the collar is arrested at that point, although the shaft C and wheel E continue to revolve as before. On the under side of the wheel E are four wedge-shaped cams E E_1, and after the shaft C and wheel E have moved through a quarter of a revolution, the collar remaining stationary, the next succeeding cam strikes the head of the pawl, forcing it back into its original position. At the same time a catch drops into the next succeeding groove in the collar B, which then revolves with the shaft C, until arrested by the depression of another key.

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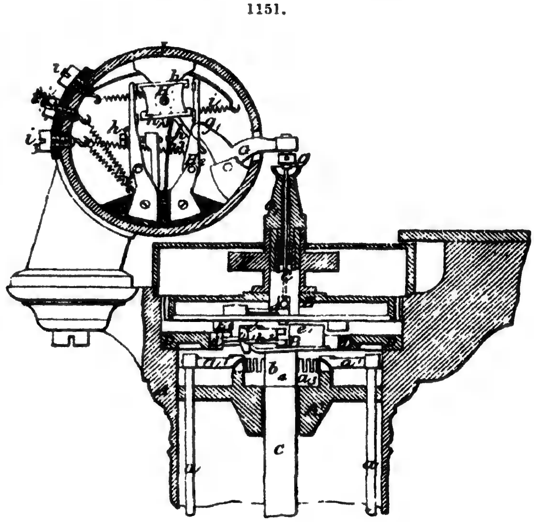


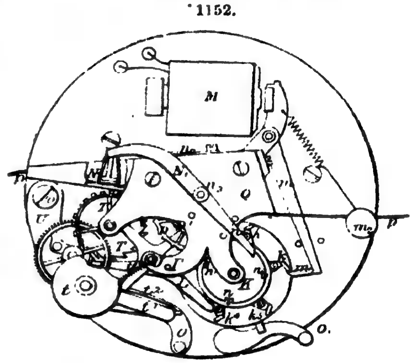
When the key is depressed no action takes place, until the head of the pawl in its revolution arrives at the corresponding slide-rod head, and the collar is immediately arrested during the time in which the shaft C is making a quarter of a revolution. At the end of this time it is released by the automatic action of the mechanism, and permitted to revolve with the shaft as before; while the collar B is stopped, the bevelled end of the pusher e passes over the projection e_1, raising the rod c, within the hollow shaft C, and operates the circuit closer. As the shaft c makes four revolutions a second, the collar B is stopped for $\frac{1}{16}$ of a second by the depression of each key, and as the length of the projection e_1, which determines the length of time during which the rod is elevated, and the circuit closed is one-eighth of the circumference of the collar, the duration of the electric pulsation produced by the elevation of the rods c will be $\frac{1}{32}$ of a second.

The circuit closing mechanism admits of either the single current or the double current system being employed, by change of connection. This part of the apparatus is enclosed in a cylindrical

case I, fitted with plate-glass heads. H is a quadrangular plate of ivory mounted upon a rock shaft, upon which is also fixed an arm projecting downwards; upon the upper and lower edges of the insulating plate H, are fixed metallic bars h h_1. A spiral spring attached to the insulated screw i, takes hold of a short arm projecting upward from the axis of H, and the tension of this spring keeps the arm h pressed against the friction roller g_1, upon the lever G, and the latter in turn presses downwards by means of the adjustable screw g upon the vertical rod c. The spring also serves to conduct the electric current from the screw i_1, which is connected with the negative of the main battery, to the bar h_1; a second screw directly behind i_1 and insulated from it, is attached to the copper pole of the battery, and is also connected by means of a curved wire and spring i to the metallic bar h_1. H_1 and H_2 are two upright contact levers connected respectively to the line wire, and to the earth. When the apparatus is arranged for the double current system, the negative current flows to line at all times, when none of the keys are depressed, but when the rod c is raised, by the action of the transmitting mechanism, the polarity of the current upon the line is reversed, by the action of a lever G upon the arm h, shifting the position of the plate H, and bringing the negative pole of the battery into connection with the earth. Pulsations thus transmitted are conducted through a relay, connected with the sending as well as the receiving instrument. With the double current system a polarized relay is used.

The printing mechanism, Fig. 1152, is arranged upon a horizontal circular plate, supported by a bracket upon the hollow column A. The type wheel T is rigidly fixed upon the same axis with and directly above the wheel T_1 of the same diameter, provided with twenty-eight ratchet teeth. The wheels T and T_1 are upon a sleeve, and are attached, by means of a friction plate, to the axis of a toothed wheel receiving its motion from a wheel not shown in the Fig., through the intervention of an idle wheel. As these wheels have each the same number of teeth, they must revolve synchronously. The type wheel T is inked by means of an ink roller t, mounted upon a horizontal swinging arm, and constantly pressed against the type wheel by a spring; the star printing wheel K controls the mechanism, and itself is under the control of another electro-magnet M; it arrests the type wheel when a letter is to be printed, forces the platen and paper into contact with the type wheel, moves the paper forward after the letter has been printed, and releases the type wheel. The electro-magnet is actuated by a battery connected with the receiving relay. To its armature is fixed a lever m, armed with a detent m_1, which takes hold of one of the points k of the printing wheel, when no current is passing through the magnet. The detent is kept in position by a spring. The printing wheel K, being connected to a wheel by a frictional coupling, revolves with the latter when not kept in check by the detent. The printing wheel K has six angular studs or pallets projecting from its circumference, to serve as stops, upon which the detent m_1 successively acts. Two concentric rows of vertical pins are inserted upon the upper surface of the printing wheel, and there are six of these pins in each row; the outer row of pins k, acts upon the stop lever which arrests the type wheel on the inner row n, and acts upon the platen and upon the mechanism while moving the paper. Between each pair of pins k, n, is placed a central circular pin.

1152.



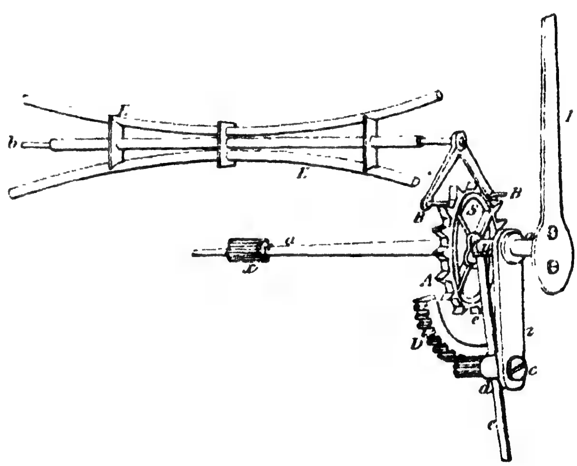
When a letter is to be printed the detent m_1 is lifted by the action of the electro-magnet, the pallet k is released, and the printing wheel K carried forward one-sixth of a revolution, by its frictional connection with the wheel beneath it. This movement of the printing wheel produces the following results. An angular projecting stud at the end of the type-wheel stop lever L is caused to pass between the pallet k_4 and the pin; as this lever turns upon a fulcrum at I′, the detent l at its opposite extremity is inserted between two teeth of the wheel T_1 and the elevation of the type wheel T is arrested. When the circular pin moves round, it bears against the inclined surface of the stop, and forces the lever L into the position by which the type wheel is locked. The lever is retained in its position by a pin as it glides along the curved surface, holding the type wheel in check until the inclined face of the succeeding pallet k_8, coming into contact with the inclined surface upon the lever L, returns the latter to its normal position in readiness for the next rotation. Upon the release of the printing wheel K by the detent m_1, the type wheel is arrested and held in check while the printing wheel makes one-sixth of a revolution, and is then released. The device for moving the paper forward is a modification of the mechanical movement known as the Geneva stop, the convex tooth being omitted. In all type printing systems it is necessary that the transmitting mechanism of one instrument and the type wheel of the other should be in exact correspondence, and to effect this means must be adopted to ensure their starting together. In the Hughes' instrument this is accomplished by a simple stop lever, and in Phelps's printer the type wheel is automatically arrested at the zero point, whenever it is permitted to make a few revolutions without printing. Upon the upper surface of the wheel T_1, Fig. 1152, directly under the type wheel is a pin, filed to a flat surface on the side towards which the wheel revolves. J is a three-armed stop lever turning upon a fulcrum. U is a toothed wheel mounted so as to revolve freely upon a pin fixed in the horizontal lever O, by means of which it may be thrown in or out of gear with the corresponding pinion in the type wheel axis, at the pleasure of the operator. Ordinarily it is kept in gear with the pinion, and receives from it a slow rotary motion. A curved arm fitted to the arm of the stop lever J, is constantly pressed against the revolving axis of the wheel U, and has the effect of slowly and continuously swinging the stop lever J towards the left, whenever the type wheel is in motion.

If the printing wheel K continues stationary, in the course of four or five revolutions of the type wheel, the lever J will swing round into such a position, that the stop which projects downwards from the end of the arm, will be thrown into the path of the stop upon the wheel T_1, which will come into contact with it in its next revolution. The type will be arrested with its dash or blank space opposite the platen, where it will remain until the printing mechanism is again operated. Immediately the printing wheel K is released, by the action of the electro-magnet, the stop lever J is thrown back into position, because its third arm lies in the way of the second pin of the circular series upon the printing wheel. So long as one or more letters are printed at every revolution of the type wheel, a continual succession of the pins will strike against the arm, and prevent the stop lever J from being swung far enough to arrest the type wheel, unless the operation of printing is suspended during several successive revolutions of the type wheel axis, and the type wheel will be automatically arrested. The electro-motor and its governor are mounted upon the base of the instrument, and consists of eight electro-magnets arranged in a circle within which a revolving shaft turns a circle of soft iron armatures. The magnets act successively as the armatures come within their influence, and cease to act just as the armatures arrive opposite to the poles of the magnets; by this means constant attraction is exerted upon the armatures. The motor is provided with a centrifugal governor, which acts to reduce the quantity of electricity flowing through the magnets, whenever the speed is too great. The local battery which drives the motor consists of two large Bunsen cells, charged with Poggendorff's bichromate solution in contact with the carbons in the porous cell, and diluted sulphuric acid in the outer or zinc cell; these cells being 5 in. diameter and 6 in. in height. This is sufficient battery power to run the motor continuously for fifteen hours, without requiring renewal of the bichromate solution. The system is worked direct at full speed, without relay, between New York and Chicago, a distance of 1000 miles.

Figs. 1153, 1154, relate to Wheatstone and Stroh's devices introduced in 1872 in the construction of step-by-step telegraphs, the object of which is to enable the indicator of a large dial, or the dial itself, to be moved rapidly with the same certainty as the indicators of small dials.

To attain this object the propelment of the index is due to the action of a maintaining power, limiting the work performed by the transmitted currents to the controlling of the scape wheel, a special arrangement obviating the retarding effect due to the weight of the index hand.

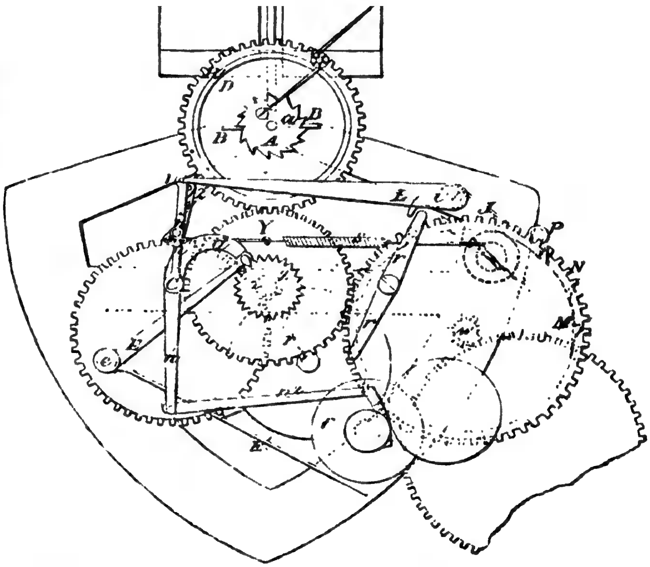
On an axis *a*, Fig. 1153, driven by clockwork gearing with the pinion *x*, is firmly fixed an index hand P and an arm *z*. At the extremity of this arm a pinion *d* centred at *c* and gearing with the stationary wheel D, a segment only of which is shown, carries two equal arms *e e*. Mounted loosely on the axis *a* is a scape wheel A, to which one end of a light spiral spring S is attached, the other end being fixed to the axis *a*, so that the scape wheel remaining stationary and the axis *a* revolving, the spiral spring S would be wound up, and conversely the axis *a* remaining stationary and the scape wheel free to move, the spiral spring in unwinding itself would tend to propel the scape wheel forwards. To the centre of the scape wheel A is fixed the piece *f* carrying at its extremity a stop *n*, which when the scape wheel is at rest is met by the end of one of the arms *e e*, attached to the pinion *d* or to its axis, and thereby the revolution of the axis *a*, and consequently the pointer P, prevented. The control of the scape wheel is effected by the pallets B B, to which an oscillatory motion is communicated by any suitable electro-magnetic arrangement, such as that shown at E E, in such a way as to allow the scape wheel to advance with a step-by-step motion, one half tooth for every movement of the pallets. It follows that with every movement of the pallets B B, the scape wheel A driven by the spiral spring S will advance, and this forward movement of the scape wheel will, by withdrawing the stop *n*, release the arm *e* and allow the maintaining power gearing with the pinion *x* to propel the axis *a*, the pointer P, and the arm *z*, and thereby to wind up the spiral spring S. The pinion *d* carrying the arms *e e*, at the extremity of the arm *z* and gearing with the stationary wheel D, will thus rotate like the sun and planet movement, until the scape wheel coming to rest locks the whole again, by presenting the stop *n* to either of the arms *e e*. The number of teeth on the pinion *d*, the stationary wheel D, and scape wheel A, are so arranged that for every half tooth of the scape wheel liberated by the pallets B B, the arms *e e* attached to pinion *d* make one half revolution. The pointer P advances one space on the dial for every half tooth of the scape wheel so liberated, and thus while the movements of the pointer are independent of the step-by-step motions of the scape wheel, the latter completely controls the starting and stopping.



In applying this arrangement to type printing telegraphs, it is used for regulating the motion of the type wheel, and the stamping of a letter on the paper strip is effected automatically, immediately after the cessation of the last of the electric currents necessary to bring the type wheel to the requisite position.

Mounted on the axis *a*, Fig. 1154, in place of the index hand is a wheel R, gearing with another wheel Y fixed firmly on the arbor of the type wheel. By means of these wheels the maintaining power moving the type wheel is controlled by the pallets B B. Also mounted on the arbor of the type wheel is a saw-toothed wheel Z, and in play with the teeth of this wheel is a pin fixed into the extremity of the arm E, this arm being centred at *e* and continued in a light rigid bar E[1], bearing on a friction wheel *f*. During the rotation of the wheel Z the pin cannot rest between any of the teeth, and the arm E is therefore kept up. The pin on E passes in its upward motion against a segmental arm *d* centred at C, at which also is centred the arm *n* bearing against a pin in the segmental arm *d*, and sustains these two arms, keeping the releasing arm L, which is centred at *i*, free from the pin 1 at the end of the arm *n*, and allowing a bent end of the releasing arm L to rest upon the pin 2 in the arm *y*, which is centred half-way up the arm *n* and kept in position by a spiral spring S. A continuation n^1 of the arm *n* has pivoted at its extremity a light bar n^2 bearing upon friction wheels.

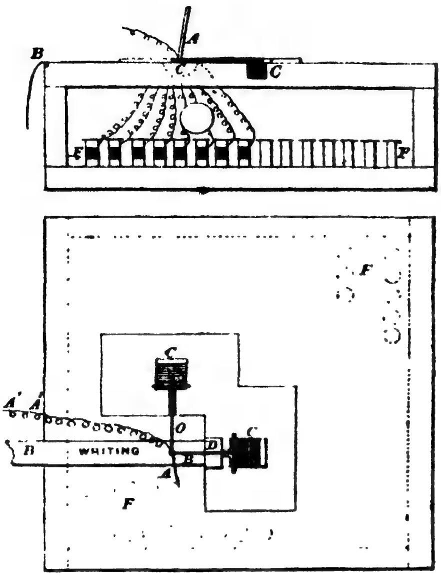
1154.



When the rotation of the wheel Z ceases the pin on E and the arms *d* and *n* fall, and before the end of the releasing arm L can engage with pin 1, the check piece is liberated from its position of rest on pin 2, and the arm L falls. A transverse groove in the arbor of the arm L retains the end of a piece J, jutting from the axle of a pinion P, gearing with a wheel N fixed on the arbor of a second wheel M, having widely spaced teeth, and called the stamping wheel. With a pinion *w*, also on the arbor of the stamping wheel, a maintaining power, separate and different from that imparting motion to the type wheel, is in gear. The fall of the arm L liberates the piece J, and this piece in making one revolution before it again engages in the groove of the arbor of the arm L, permits the stamping wheel to be carried forward one tooth by the maintaining power in gear with it. The tooth of the stamping wheel coming into contact with a touch piece, causes the printing hammer to be lifted against the rim of the type wheel. Consequently, the letter immediately presented to the face of the printing hammer, is printed on the paper strip which intervenes between the type wheel and the hammer. The action on the printing hammer is direct, but in the case of the arm L a series of levers *r*, *r*, *r*, are brought into play. The type wheel is adjusted to zero as in Fig. 1153.

Fig. 1156 is a plan of sending instrument of E. A. Cowper's writing telegraph, Fig. 1155 being an elevation of the same. The writer holds the pen, which is rigidly connected to the travelling contacts, and also, as at A^1 A^2, to the batteries. The slip of paper on which the message is written is moved somewhat in the same way as in a Morse instrument; in fact, the Morse clockwork can be easily used for the purpose. Thus the paper travels under the pen instead of, as in ordinary writing, the pen travelling over the paper. Two sets of thin metal plates C C form the contact apparatus, D are the light connecting rods, the ends of which make contact with the plates; F F are the resistance coils connected to the contact plates, one coil for each plate, except the first of the series, which is connected to line. It will be noticed that the strength of the current entering the line, depends upon the plate with which contact is made by the connecting rod. As the rod travels from the first of the series the resistance increases, the current having to pass through $N - 1$ resistance coils, as well as the line wire, N being the number of plates from the first of the series, to the point at which contact is made. Generally, however, as one contact piece travels from the first of the series, the other travels towards the first of its series, and thus, while the current decreasing varies in one line, the variation is increasing in the other. A slight knowledge of co-ordinate geometry is required to plot the curve of any letter, and to calculate the variations in the strengths of the currents. Figs. 1157 and 1158 are respectively an elevation and plan of the thin metal plates, which are insulated the one from the other by paper soaked in paraffin. The receiving instrument, Figs. 1159 and 1160, differs from the sending instrument; H H are light, soft iron bars on delicate bearings, having the ends surrounded by the coils I I, to which the bars form

a movable core. Through these coils the varying currents of the line are sent, which, of course, have a varying action on the core. J J are four permanent or electro-magnets, between the poles of which the coils just named are placed; K is a Clark siphon pen, which is adjustable from the bridge L, and the ink reservoir is at M. The light connecting rods N N transmit the motions of



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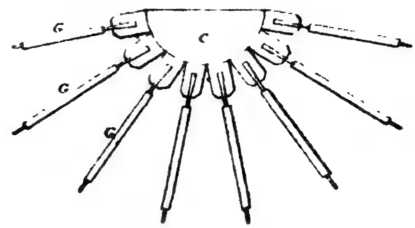

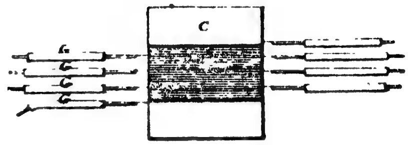

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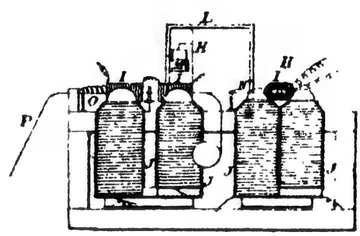
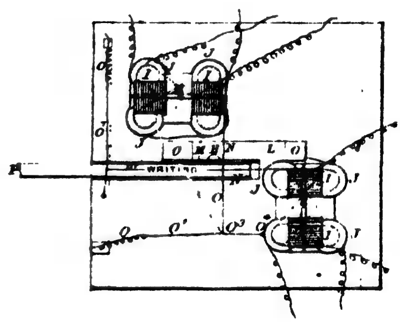
1159.





1160.

the movable cores to the pen; O O are springs to enable the pen to resist the pull of the magnets, the connections are shown in O^1, O^2, O^3, the latter being attached to a fixed post O^4.

As the currents sent through the line wire by the sending instrument vary in strength, and cause the light bar of soft iron to move with varying power by its attraction to the stationary magnets; and in order to cause it to take its proper position according to each vibration in power, a varying resistance is opposed to it, such as a spring which requires increased power to compress it the more it is compressed, so that the action of the soft iron bar, combined with that of a precisely similar bar actuated by the second line wire, will cause the position of the pen in the receiving instrument to follow the position of the pen in the hand of the operator at the sending instrument, and thus form the letters. The total strength of the spring or varying resistance can be regulated at will, so that the letters formed by the pen shall be of the same proportionate height and width, as the letters written by the operator at the sending instrument.

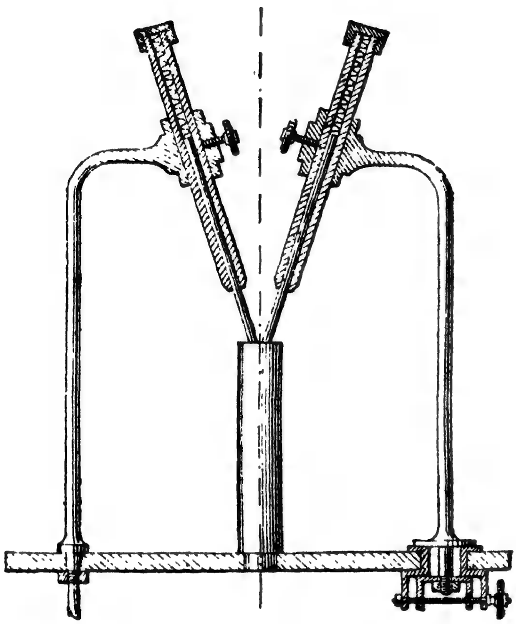
Electric Lamps.—Electric lamps or burners may be divided under two heads: those in which the voltaic arc is caused to exist between the two portions of an interrupted circuit; those in which a continuous portion of the circuit, being a bad conductor, is heated to incandescence by the passage of the current. It is probable that this division being arbitrary and not generic, may at any time be overturned by a new invention based upon principles that do not appear in lamps at present invented.

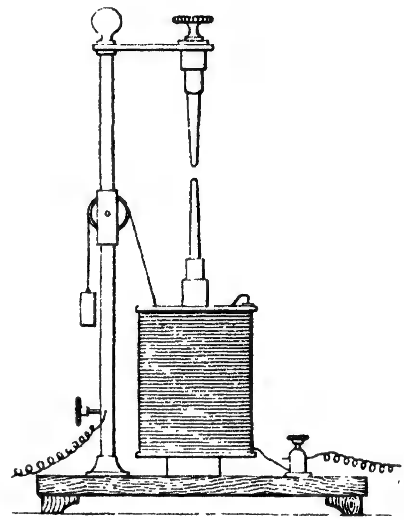
Foucault, in 1844, substituted retort carbon for common wood charcoal, as the substance for electrodes, and this discovery opened up a practical application of the electric light to photographic purposes. The lamp was simply a holder for the carbon rods, and required help from the hand of the operator. Trials of the light were made in the Place de la Concorde, Paris, by M. Deleuil, who had previously experimented with carbon placed in a receiver from which the air had been exhausted.

Staite and V. Edwards, in 1846, introduced a lamp, Fig. 1161, in which two carbon electrodes in small cases, meeting obliquely on a refractory and badly conducting substance. The are brought into place, as consumed, by springs. A sliding-piece and screw beneath the base enable the length of the voltaic arc to be regulated.

Staite and Petrie, as well as Foucault, in 1848, devised a method by which the current regulated the distancing of the carbons. This was based upon the phenomena that an electric current can cause magnetization according to its strength; that the voltaic arc as part of the conductor, reacts upon the current. This lamp, however, was never introduced into practical use; in principle it was similar to Archereau's lamp.

Fig. 1162 is of Archereau's lamp, the basis of many ideas, and one of the most simple and effective of its kind. It consists of a hollow coil of copper wire, with a vertical standard, two carbon





carriers, and a counterpoise. The upper carbon is carried by a bar, sliding into and turning at the extremity of an insulated horizontal copper bar, in connection with the negative pole of the electric source. The lower carbon rests on a cylinder, half of copper, half of iron, rising or falling in the hollow bobbin. The positive pole of the electric source is attached to one end of the wire coil, and the other end to the interior cylinder of the coil; a weight counterpoises the lower carbon holder. When the current passes in the wire, it produces magnetic action, causing the cylinder to descend into the bobbin, and to reduce the strength of the current. When the magnetism is too weak, the action of the counterweight raises the cylinder. Initially the carbon points must be brought into contact, to establish the electric circuit. When the voltaic arc is formed, the cylinder remains fixed in the coil, and the counterweight is motionless. As the voltaic arc increases in length, and the current is weakened, the lower carbon rises, until the current again attains sufficient power.

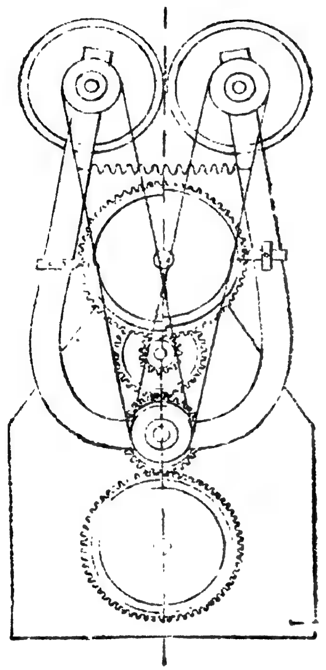
T. Wright, in 1845, caused the voltaic arc to play between discs of carbon, and Le Molt, in 1849, improved upon this idea. Fig. 1163 is the lamp described. Le Molt claimed the use of all carburetted matter, as electrodes producing the light, especially that of retort carbon, and the two combined movements of rotation and approximation, at given intervals, of two discs of variable depth and diameter. The discs are maintained, with regard to one another, in a parallel attitude, vertical or horizontal, or preferably, in positions at right angles, and conveniently distanced to produce the electric light. The discs revolve regularly upon two metal axles, put into connection with the poles of the generating apparatus, and presenting, successively, by the combined rotation and approximation, all the extreme points of their circumferences to the production of the light; in such manner that at each revolution of the discs, the latter approach one another by the distance which they had separated by the combustion of part of the carbon, and thus are always replaced in the same position of invariable distance. Le Molt introduced the purification of the carburized matter forming the electrodes, by more or less prolonged immersion in nitric and muriatic acids, and subsequently in fluoric acid. This lamp allowed of twenty to thirty hours' continuous light; but the intensity of the light is less than that obtainable with vertical carbon rods.

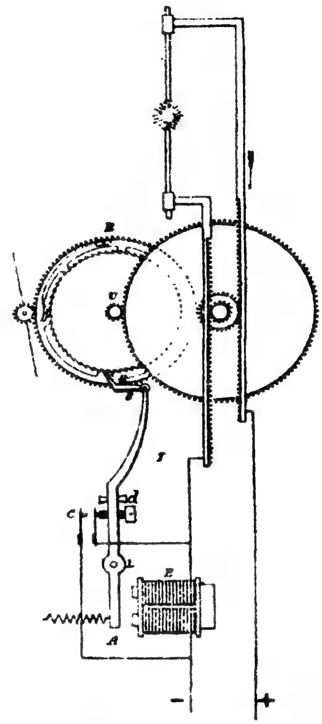
Another typical form of lamp is that of Lacassagne and Thiers, who, in 1855, substituted for clockwork, which had then been introduced into lamps, a float acting in a bath of mercury. A cylinder contained a float upon, and in connection with, the mercury; one carbon electrode rested upon this float. The other carbon electrode was fixed in the same axial line above the electrode supported on the float. As the carbon points consumed, so the float rose; but a means of arranging the rise to occur at the proper time was necessary, and was thus supplied. Mercury from a reservoir, having entered the float cylinder, passes through a tube placed in an electro-magnet. In this tube

is an indiarubber valve, opened and closed by a soft iron armature, withdrawn by a spring opposing the action of the electro-magnet. The opening of the valve admits mercury to the float cylinder. As the distance between the electrodes increases, the magnetic attraction decreases, and the valve opens, the incoming mercury raising the electrode.

This lamp is the basis of many subsequent ideas, some of which omit the regulating apparatus, and employ the mercurial bath simply to raise the carbon rod against a disc of carbon, as the rod is consumed.

These lamps, however, have not, as constructed by their inventors, met with practical application. The various modifications introduced do not detract from the merit of the original inventions,





but are additions that have become expedient, under somewhat different circumstances attending the use of the powerful currents derived from magneto- and dynamo-electric machines. If the accounts were continued chronologically, there would follow a description of Duboscq and Foucault, in which clockwork was employed to distance the carbons. These will be presently referred to, but it is first necessary to point out that all complication is to be carefully avoided, and that a lamp to be effective must need no skilled attendance, such as a clockwork movement would entail.

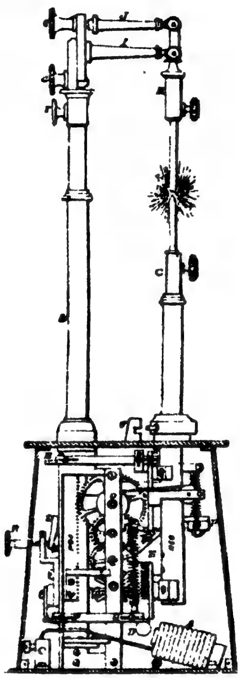
Lamps in very general use are the Siemens and the Serrin. In the Alteneck-Siemens lamp, Fig. 1164, the position of the carbons is regulated by the weight of the upper carbon holder, which tends to bring the carbons together. The carbon points are separated by a small electro-magnetic motor. The upper carrier is connected to the lower by rackwork and tooth wheels. When, by reason of the carbon points approaching too closely, the current becomes too strong, the electro-magnet E attracts the armature A, held back by a spring, which keeps the lever T, centred at L, against the stop *d*. When the electro-magnet overcomes the effort of the spring and attracts the armature, contact is made at *c*. Immediately the current ceases to pass through the magnet, the armature is released. The lever T is thus kept in oscillation and communicates by a pawl *s* a rotary motion to a fine tooth wheel U, and by the help of the train and racks separates the carbons. A pin R, against which the pawl strikes when the armature is retracted by the spring, compels the pawl to leave the teeth of the ratchet wheel, and allows free motion to the racks. That the carbons may not run together too rapidly, a fly *w* is employed.

If alternating currents are used with this lamp, the oscillations of the armature are produced, not by making and breaking contact, but by change of polarity of the current.

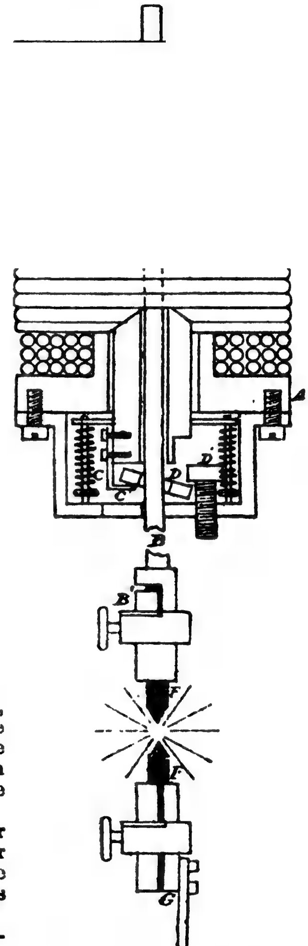
Several other forms of lamps have been introduced by Siemens. One of these, on the principle of the Archereau lamp, has its carbons separated by the action of a cylindrical armature which is drawn into a hollow bobbin. In another form, the carbons are placed inclined to each other side by side, one being pivoted at its lower extremity, to which is attached a short arm carrying an armature of an electro-magnet. As soon as the electro-magnet, which is in the lighting circuit, is excited, the carbons are drawn apart and the arc established between them, as in the Rapieff and Wilde systems, to be presently described.

Serrin's lamp, Fig. 1165, consists of an electro-magnet A, a bar B, a bar C carrying the negative carbon, an armature D, abutment E, spring F, excentric G, positive carbon holder H, tie piece, fixed, I, adjustable tie piece J, tension lever K L, double parallelogram M N P Q, train of wheels O, adjusting screws R and S, clamp screw T, and ivory stop V. The weight of the top carbon causes the points to be brought together. The top carbon holder bar is racked at its lower end, and in its descent engages with a tooth wheel of the train O. On the same axle is a pulley of diameter half that of the wheel. This pulley follows the motion of a smaller pulley, by means of a link chain. The chain is fixed to a standard F, attached to the tube of the negative carbon holder. According to the dimensions of the first pulley the negative carbon holder is carried to a distance half that through which the lower carbon holder descends. The descent of the upper carbon is regulated by a fly, which also carries a star wheel.

1165.



1166.



The proper distance between the points is obtained by means of the double-jointed parallelogram M N P Q, controlled by the soft iron armature D and electro-magnet A. The influence of the weight of the carbon holder on the jointed parallelogram is counterbalanced by two spiral springs, one attached to the lower horizontal side and to a fixed arm, the other, connected to the movable vertical side of the parallelogram, is also attached to the end of a bent lever L K, and can be adjusted to the screw R. The distance through which the armature D is attracted varies with the intensity of the current. The bar of the negative carbon holder is connected to the vertical moving side of the parallelogram, which is submitted to two counterbalancing forces, the weight tending to cause it to fall, and the springs to raise it. The action of the electro-magnet is to cause the parallelogram to descend. The vertical movable side of the parallelogram carries a jockey E, the point of which, as it descends, enters between the arms of the star wheel, detaining the movement of the train and racks. The distance of the carbons apart, giving the best light for mean strength of the current, is regulated by the tension given to the spring in connection with the lever L K.

Girouard's lamp regulator consists of a clockwork movement for bringing together and separating the carbons; and a regulator or relay, placed near the lamp and operated by a small battery. The relay receives a small amount of the lighting current and controls the clockwork movement.

Carré's lamp employs a double solenoid instead of an electro-magnet. The armature solenoid is S-shaped, and is centred so as to enter at each of its extremities into a hollow curved bobbin. The object of this arrangement is to obtain greater space, through which the carbons may be separated, than is obtainable with an ordinary electro-magnet and its armature.

Foucault and Duboscq's lamps, superseded in the lecture-room by the Serrin and other lamps, contain a clockwork movement, which has to be wound up, regulated by escapement, which is controlled by an electro-magnet in the circuit.

Gaiffe's lamp is a modification of that of Archereau, with the addition of a rack and pinion for raising the top carbon, which is aided in its descent by a spring that is coiled when the carbons are drawn apart. The electro-magnet is covered with more convolutions at the base than at the top, so that when the current becomes weakened by the separation of the carbon points, it may have its magnetic effect still powerfully maintained.

Fig. 1166 is a section of one of the Brush lamps; A is a helix of insulated wire, A′ an insulated plate, C an iron core, B a rod, D a brass ring, F F carbons, G lower carbon holder. The Brush lamp contains no clockwork or similar mechanism, and the movement of the upper carbon, actuated by gravity, is controlled by an annular clamp, which surrounds the rod carrying the carbon. When the lamp is in operation, one side of this clamp is lifted by magnetic action; this causes it to grasp and raise the rod, and thus separate the carbons. As the carbons burn away, the magnetic action diminishes, and the clamp and rod move gradually downward, maintaining only a proper separation of the carbons; but when the tilted clamp touches the supporting floor from

which it started, any farther downward movement releases the rod, and allows it to slide through the clamp, until the latter is again brought into action by the increased magnetism due to the shortened arc between the carbons. In continued operation, the normal position of the clamp is in contact with its lower support, the office of the controlling magnet being to regulate the sliding of the rod through it. If, however, the rod accidentally slides too far, it will automatically be raised again, and the carbon points maintained in proper relation. Each magnet helix is first wound with a few layers of coarse wire, through which the main portion of the current passes. Over this coarse wire is wound a very much greater length of fine wire, not shown, having its ends connected with the terminals of the lamp, but in such a manner that the electric current shall pass through it, in a direction opposite to that in the coarse wire. The fine wire forms a circuit of high resistance, which is independent of the arc between the carbons, and is always closed. It follows from the difference in direction of the current in the two helices, that the fine wire helix will constantly tend to neutralize the magnetism produced by the coarse wire or principal helix. The number of convolutions of the fine wire helix and its resistance are so proportioned to the number of convolutions in the principal helix and its resistance, together with that of the normal voltaic arc, that the magnetizing power shall be much greater. Notwithstanding the small amount of current which passes through the fine wire helix, about 1 per cent. of the whole current, its magnetic power is considerable, owing to its great number of convolutions.

When a number of regulators provided with these double helices are operated in a single circuit, uniformity of action will be maintained; for when any lamp gains more than its normal arc, the resistance of its main circuit is increased; more current is consequently shunted through its secondary helix, and the resultant magnetism is diminished, allowing the carbons to approach. On the other hand, if an arc becomes too short, its resistance is reduced, and less current is shunted through the corresponding helix, and its carbons are drawn farther apart. Although the general strength of the current, operating a large number of these lamps, does not vary, each lamp performs its regulating functions through the agency of varying magnetism, precisely as though it were the only lamp operated. In practice, the resistance of the fine wire helix or helices in each lamp is rather more than 450 ohms; while the resistance of the coarse wire, various connections, carbons, and voltaic arc, in each lamp used with a 16-light machine, is about $4\frac{1}{2}$ ohms. Hence not more than 1 per cent. of the whole current is diverted from the arc.

The resistance of the coarse wire helix, copper-coated carbons and connections, in each lamp is very small. To determine this resistance, sixteen lamps were connected in series in the usual manner, about 200 ft. of No. 10 copper circuit wire being used. Full-length carbons were then placed in the lamps, and the upper and lower carbon of each lamp were connected by means of a strip of sheet copper, wired to each carbon. The resistance of the whole set was then measured, and found to be 2·10 ohms, showing a resistance for each lamp with its carbons, of ·139 ohm. This is 2·91 per cent. of the whole resistance of the lamp when in operation. To this loss must be added the 1 per cent. due to that amount of current diverted from the arc by the fine-wire regulating helix, making a total loss of 3·91 per cent. The remaining 96·09 per cent. of the whole energy absorbed in each lamp, appears in the arc between its carbons.

The shunting or short circuiting device in each lamp, consists of a small magnet core, surrounded by a coarse and a fine wire helix similar to those of the working magnet. No current passes through the coarse wire until the magnet which it surrounds has raised its armature. The latter, together with the coarse wire, then form a part of the short circuit established through the lamp. The fine wire helix of the shunt is put in the circuit of the fine-wire regulating helices. During the normal operation of the lamp, this fine wire helix exercises a magnetizing influence on its enclosed core, which thus attracts its armature with a certain degree of force, but not enough to lift it. But when, through the exhaustion of the carbons in the lamps, or from their failing properly to feed together, the arc between them becomes considerably lengthened, developing an abnormal resistance, an increased current will be shunted through the fine wire helix, the iron core of the latter will raise its armature, and establish a circuit of low resistance independent of the carbons.

When the short circuit is closed, very little current circulates in the fine wire helix, and the magnet would drop its armature and open the circuit, were the armature not retained by some means other than the magnetism due to this helix; but the coarse wire helix surrounding the same iron core is now brought into action, and the armature is retained.

The carbons employed in these lamps are covered with a thin coating of copper, and are 12 in. long. They burn, without renewal, about eight hours, and during this time about $9\frac{1}{2}$ in. of the positive, and 4 in. of the negative are consumed. When it becomes desirable to operate the lamps more than eight hours continuously, double-rod lamps are used. In each of these lamps two movable rods and two sets of carbons are employed. The rods are placed 3 in. apart, and each is moved and controlled in the manner described. Both rods are actuated by a single magnet, the same as that employed in the single-rod lamp. The simple lifting mechanism connected with the magnet is so arranged, that one of the rods is lifted slightly in advance of the other. When the electric current first passes through such a lamp, the two sets of carbons, having their members in contact, will divide the current between them; but as soon as the members of one set are separated by the action of the magnet, the whole current is thrown through the other set, without showing any spark between the members of the set first separated. When the continued action of the magnet separates the remaining pair of carbons, the voltaic arc appears, and the light is established. The clamp which was the last to raise its rod will be the first to release it, when a forward movement of the carbon becomes necessary. Hence, the set of carbons which first commenced to burn, will continue to do so until consumed, the other set remaining separated as at first. But when the burning carbons are exhausted, and can no longer move forward, any further effort of the magnet to feed them, will at once bring the reserve set of carbons into contact; the whole current will then pass through this set, leaving the other carbons without current, and permanently separated. The reserve set of carbons will now be separated by the magnet, and burn continuously. In prac-

tice, the transfer of the voltaic arc from one set of carbons to the other is accomplished instantaneously, and is scarcely noticeable.

By means of these double-rod lamps, a system of lights may be maintained in continuous operation sixteen hours without attention. This is sufficient for the longest winter night. But by introducing three rods, and three sets of carbons in each lamp, the lights may be maintained for twenty-four hours. In this case the clamps lift their rods successively, and feed them in the reverse order, as before.

In working, sixteen lamps are employed on one circuit, which for 200 ft. may be No. 10 copper wire, and each of the sixteen lamps normally, has an arc of about one-twelfth of an inch.

Measurements have been made for the purpose of determining the difference of potential between the terminals of each lamp, with the sixteen lamps adjusted to furnish arcs as nearly equal as possible. An opposing battery method was employed, and gave as result a difference of 42·46 Daniell's elements.

As the report by C. F. Brush includes the only published measurements of the power absorbed in working more than one light on a single circuit, the resistance of the components of the circuit and the distribution of work are given in the following statement:—

Expenditure of Power in Working Sixteen Lights on a Single Circuit. Brush System.

Resistance of dynamo-electric machine	10·55 ohms.
Resistance of external circuit	72·96 „
Total resistance of circuit	83·51 „
Resistance of voltaic arcs	70·86 „
Percentage of current available for external work	87·36 „
Percentage of current appearing as heat and light in sixteen voltaic arcs	84·00 „
Electro-motive force of current	839·02 volts.
Volume of current	10·04 webers.
Total driving power required	15·48 h.p.
Driving power absorbed in production of current	13·78 „
Energy of current expressed in h.p.	11·285 „
Percentage of gross power converted into current	72·90 „
Percentage of absorbed power converted into current	81·89 „
Percentage of gross power appearing in arcs	61·24 „
Percentage of absorbed power appearing in arcs	68·79 „

Referring to the electrical measurements, there is a current of 10·04 webers, with a total resistance of 83·51 ohms. The value in foot-pounds of any current is ($C^2R \times t$) 0·737335, where C is the current in webers, R the total resistance of the circuit in ohms, t the time in seconds, and 0·737335 the equivalent in foot-pounds of one weber for each ohm a second. Hence, the value in foot-pounds a minute, of the current from the 16 light machine, is $10 \cdot 04^2 \times 83 \cdot 51 \times 60 \times \cdot 737335 = 332410 \cdot 58$. This divided by 30,000 = 11·285, which is the energy of the current expressed in h.p. Again,

$$\frac{11 \cdot 285}{15 \cdot 48} = \cdot 729;$$

hence, 72·9 per cent. of the total power applied at the pulley of the machine was converted into current. As 84 per cent. of the entire energy of the current appeared in the voltaic arcs, 72·9 multiplied by ·84 = 61·24, the percentage of the total driving power appearing in the arc.

If friction and resistance of air be deducted from the gross power absorbed, and the power actually absorbed in the production of current only considered, as is usual in determining the efficiency of dynamo-electric machines,

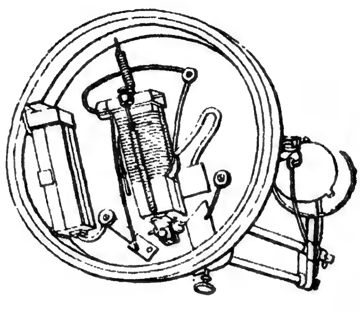
$$\frac{11 \cdot 285}{13 \cdot 78} = \cdot 8189;$$

or 81·79 per cent. of the absorbed power is converted into current. As before, 84 per cent. of this current appearing in the arcs, 81·89 × ·84 = 68·72 per cent. of the entire power is absorbed in the production of current, present as heat and light in the sixteen arcs.

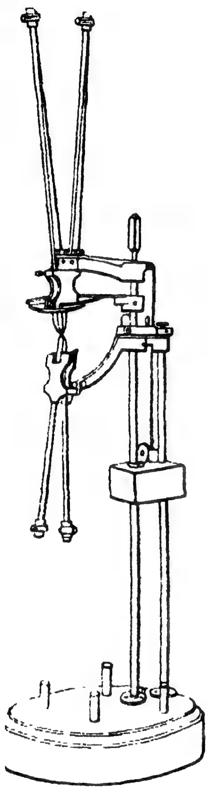
In Rapieff's lamp, Figs. 1167 and 1168, the vertical arrangement of the carbons is maintained, but instead of one positive or negative carbon, each carbon is duplicated. The duplicate parts are placed relatively to each other in the form of a V, and touch only at their ends. Each carbon passes through a holder with a small guiding wheel, at about 2 in. from the end. The current enters the carbon at this point, and is not carried through the whole length of the carbon. The resistance is thus maintained uniform. The electric arc is produced between the upper and lower pairs of carbons; and the position of the carbons is determined by the intersection of the two axes of the carbon rods, so that a constant length of arc is necessarily consequent, whatever may be the rate and irregularity of consumption. Each carbon rod moves freely between guides in the direction of its length, and is drawn through these guides by a cord and weight, to form the apex of the V with the other rod. The motion is stopped by the two carbons impinging against each other. The plane of the upper pair of carbons is at right angles to that of the lower pair. Fig. 1167 is of a lamp thus constructed. When the current is interrupted the lower pair of carbons is kept in contact with the upper pair, by the action of a light spiral spring placed in the base of the lamp, and acting through a vertical rod passing up one of the pillars. To the free end of each of the carbon rods is attached, by a screw clip, a silk thread, which, passing over pulleys, is attached to a weight sliding up and down the two pillars. This weight tends to draw the carbon pairs together. The

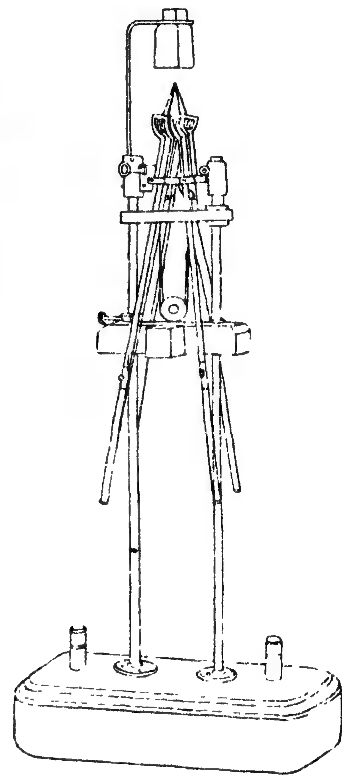
current established, the lower pair of carbons is drawn away from the upper by the action of the electro-magnet, in the base of the lamp, Fig. 1168. The electro-magnet is in two parts, one of which is fixed, while the other is hinged, so that the passage of the current through the coils causes the hinged magnet to approach the fixed one, lift the sliding rod, and separate the carbons. The base of the lamp contains also an automatic shunt, which throws into the circuit a resistance equivalent to that of the arc, when the lamp is extinguished. When the current ceases in the coils of the electro-magnet, the armature is released, and falls back against a fixed contact piece, introducing into the circuit an artificial resistance of carbon.

1168.



1167.





1170.

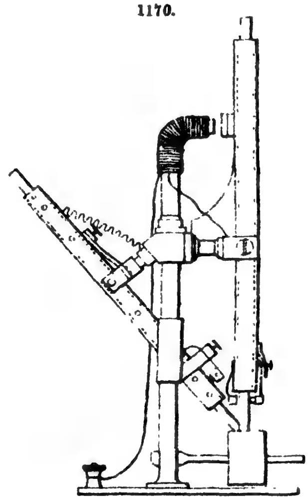


Fig. 1169 is of another form of Rapieff's lamp in which the two pairs of carbons are arranged side by side, instead of vertically above each other. Above the arc is a cake of lime, which serves to reflect the rays, as well as to maintain the illuminating power during momentary cessation of the current. These lamps can be employed with currents of single or alternate direction. In one instance, the pairs of carbons are equally consumed; in the other, the positive carbons have to be made twice as long as the negative carbons; and in either the point of intersection of the axis of the carbons, and consequently of the length of the arc, must remain constant. Six of these lamps have been worked on a single circuit, but no data are available as to the power absorbed for light produced.

Hedge' slamp, Fig. 1170, somewhat similar in form to Staite and Edwards', differs in that the voltaic arc is automatically adjusted as to length. The carbons are free to slide in tubes or guides. The two electrodes thus arranged meet at an angle on a circular block of refractory material, such as lime. When the circuit is established, the arc is caused, by the separation of the two carbon points by an electro-magnet placed in the circuit of the lamp, and shown attached to one of the guides. The block of lime is made to revolve either by gravitation of the carbon, or preferably by a small motor, in order to remove the ash of the carbon. As the lime block becomes intensely heated the light is maintained steady.

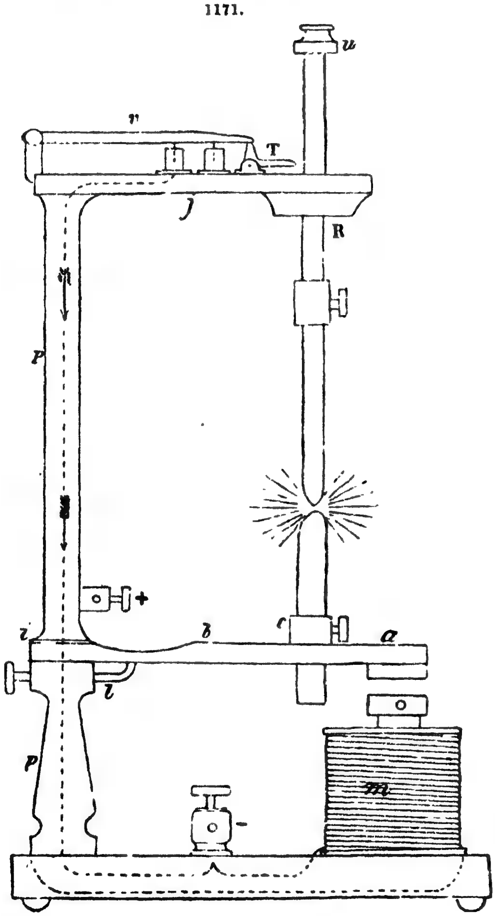
Lontin has introduced a form of lamp, in which the action of gravity is dispensed with, allowing of any length of carbon being employed. Clockwork or an electro-motor causes a bar, running parallel with the carbons, to revolve. The motion is imparted by bevelled wheels to others which cause the carbon carriers to revolve, and to carry the carbons, arranged horizontally, gradually forward. The carriers hold the carbons about 2 in. from the end of the carbon point,

reducing the resistance to that due to this length of carbon, instead of giving that of the whole length as in many systems.

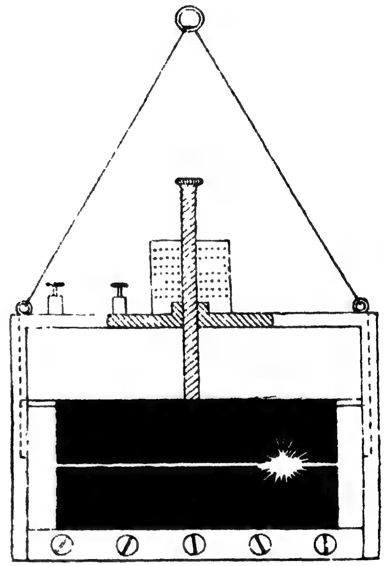
Lontin's original lamp is a modification of that of Serrin, and consists in substituting for the electro-magnet a metallic bar, so arranged that its expansion, under the heat produced by the passage of the current through it, causes the separation of the carbon points. In another form, Lontin inverts the action of the Serrin lamp, causing the current to be interrupted where, in the ordinary form, it was continuous.

In Thomson and Houston's system, one or both of the carbon electrodes are caused to vibrate. The electrodes are placed at such a distance apart that, in their motion towards each other, they touch. These vibrations are made at such a rate that the effect of the light produced is continuous. A flexible bar, *b*, of metal, Fig. 1171, is firmly attached to a pillar *p*, and, at the other, bears an iron armature, *a*, placed opposite the adjustable pole-piece of the electro-magnet *m*. A metal collar *c* supports the negative electrode, and an arm *j* the positive electrode. The pillar *p* is divided by insulation at *i*, into two sections, the upper one of which conveys the current from the positive terminal to the arm *j* and the rod R. The magnet *m* is placed in the circuit. When the current circulates, the armature *a* is attracted, and the electrodes separated; on the weakening of the current the elasticity of the rod *b* again restores contact. During the movement of the negative electrode, since it is caused to occur many times a second, the positive electrode, though partially free to fall,

1171.



1172.



cannot follow the rapid motions of the negative electrode, and therefore does not rest in permanent contact with it. The slow fall of the positive electrode is ensured by proportioning its weight. The rapidity of movement of the negative carbon may be controlled by means of the rigid bar *l*, which regulates the length of the vibrating arm.

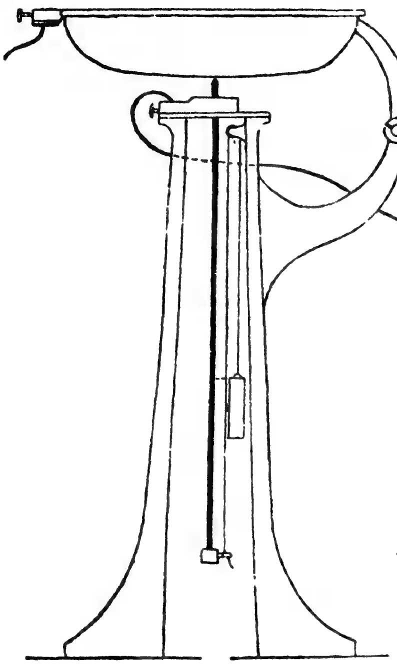
In order to prevent a break from occurring in the circuit, when the electrodes are consumed, a button, *u*, is attached to the upper extremity of the rod R, at such a distance that when the carbons are consumed as much as is deemed desirable, it comes into contact with a tripping lever T, which allows two conducting plugs, attached to the bar *b*, to fall into mercury cups, attached to the positive and negative terminals by a direct wire.

The object of the vibration of the electrodes in this system is to aid illumination by the extra spark, as well as to help the formation of a voltaic arc that is practically continuous.

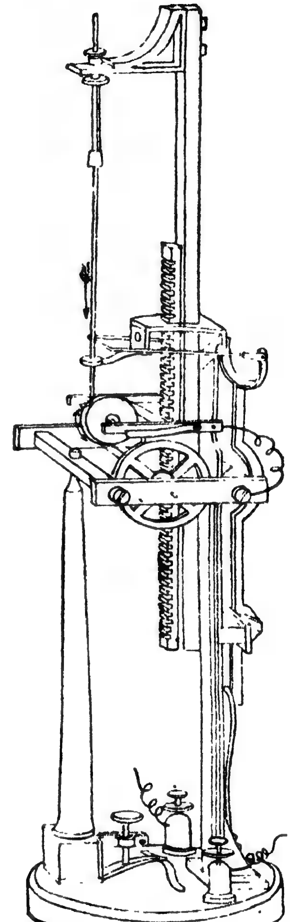
In the Wallace-Farmer lamp no carbon rods are employed; the carbons take the form of two plates, Fig. 1172, each about 9 in. long and 3 in. broad, the upper or positive plate being double the thickness of the lower plate. The lower plate is fixed, but the upper plate slides in a grooved frame. Above the frame an electro-magnetic apparatus provides for the separation and contact of the plates, as the strength of the current may regulate. The arc, always seeking the position of least resistance, shifts from point to point between the plates, as these are consumed. The plates are sufficiently large to last for a hundred hours, and six of these lamps can be burnt in a single circuit.

Fig. 1173 is of Werdermann's lamp. A block of carbon is connected to the negative pole of the electric source, the positive pole being connected to the carbon rod, which is thin, but of any required length. The carbon rod is kept in contact with the block by means of a weight and a cord passing over a pulley. The lamps are arranged in circuit in multiple arc. It might appear that this is a lamp in which illumination is due to incandescence of the carbon, but M. Werdermann contends

1173.



1174.



that repulsion between the carbon rod and disc gives a small arc, which adds greatly to the brilliancy of the light.

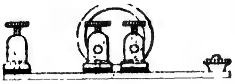
Fig. 1174 is of Reynier's lamp, different in construction, but similar in principle. The carbon rod impinges on a carbon wheel, the revolution of which is maintained either from the rackwork of the descending carbon holder, or from the tangential component of the pressure of the carbon pencil on the circumference of the disc. A brake is employed for retarding the fall of the carbon rod, and is operated entirely through the rod. The contact wheel is carried by a lever; the pressure exerted by the carbon on the wheel causes a shoe to press on the face of a wheel, which is revolved by means of the weight of the heavy rod, through its rack and pinion. Accordingly, as the point of the luminous conductor passes more or less heavily on the disc, the brake will proportionately retard the descent of the heavy carbon holder. Contact is established, not at the end of the carbon holder, but by a lateral spring contact, about ¼ in. from where the carbon presses on the wheel.

André's lamp is suitable for lighting mines, but may be applied to other purposes. In Figs. 1175 to 1177 *a a* are four carbon rods, and *b b* four copper discs, each having a small piece of iridio-platinum let into the point upon the rim touched by the rods The carbon rods *a* are enclosed in tubes A, sliding easily, and are lightly pressed down by small loose weights. *d* is an intervening button or guide piece in which the upper end of the carbon is inserted. By means of a commutator, one of the carbons only is kept in a state of incandescence at a time, and when that one is inoperative, the next carbon is automatically rendered incandescent. To prevent waste of the carbons, and as regards mines also to prevent fire-damp explosions, the carbon rods *a* are enclosed in a glass cylinder C. As the oxygen is consumed by the combustion of the carbon, the rate of wasting of the latter is gradually lessened, and in the course of, say, half an hour, the enclosed atmosphere will consist of only nitrogen and carbonic acid.

The discs *b* are connected together by a central bar *e*, and the two outer discs *b* are, by screws *f*, pivoted eccentrically to the bracket F. The negative pole is by the bracket F connected to the discs *b*. The enclosing tubes A are for this purpose connected to the positive pole through the standards D, and have each at the lower end a lever *g*, the outer and heavier end of which serves to press the carbon against the lower part of the tube A. The part of the lever coming against the carbon is hollowed out so as to partly embrace it, to produce good electrical contact, and cause the current to enter the carbon from both sides. The carbon in burning away leaves a sili-

ceous deposit on the metal disc on which it rests. This deposit causes occasional sudden extinction of the light by interrupting the current; another cause of extinction is the softening to a pasty consistency of the lower part of the carbon, causing this part to adhere to the tube at the place of contact. To obviate these disadvantages, a turning action is imparted to the disc *b*. E is an electro-magnetic core, with coils round it connected to the bracket F and to one of the outer rods, for the return of the current. The armature G of this electro-magnet is fixed to the central bar *e* of the discs *b*; H is a stopper for preventing the armature G from receding too far from the core E; K is a stopper on the opposite side for preventing the armature from approaching too near to the

1175.



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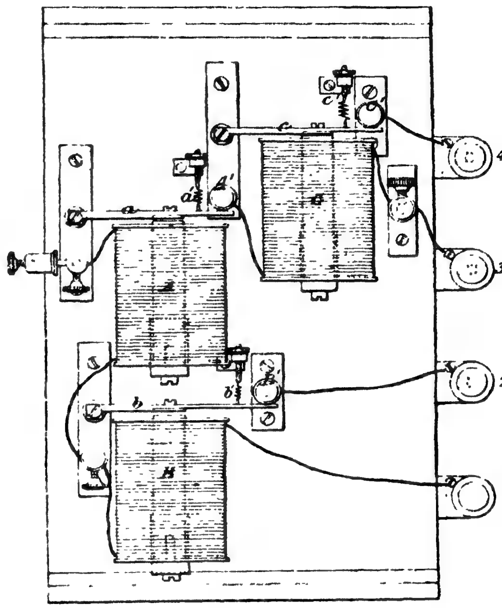
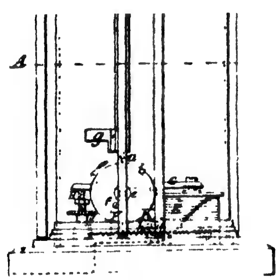
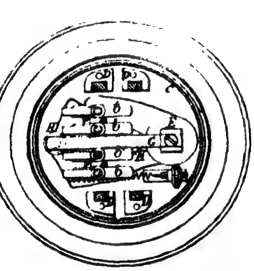






electro-magnet, and which may also be provided with a coil, connected to the rod I for the return current, but shorter than the coil on the core E; thus producing less resistance to the current, and causing a small part only to act on the electro-magnet after the armature has been attracted.

When the current passes through the coils of the electro-magnet, the armature is attracted, and the carbons are pulled over into good contact with the lower ends of the tubes. The larger portion of the current is shunted through the stop K to the terminal rod I, in order to lessen the attractive force of the electro-magnet, and to diminish the resistance. In case the current is interrupted at the place of incandescence, the armature G is let go from the position shown, and a spring *h* then turns the eccentrically mounted discs slightly in the direction of the arrow, causing the disc to rise a little, and the carbon, if stuck, to be released, and any siliceous deposit on the discs pushed away by the carbon point. When the circuit has been restored, the armature will be attracted again, and the discs turned into their former position.

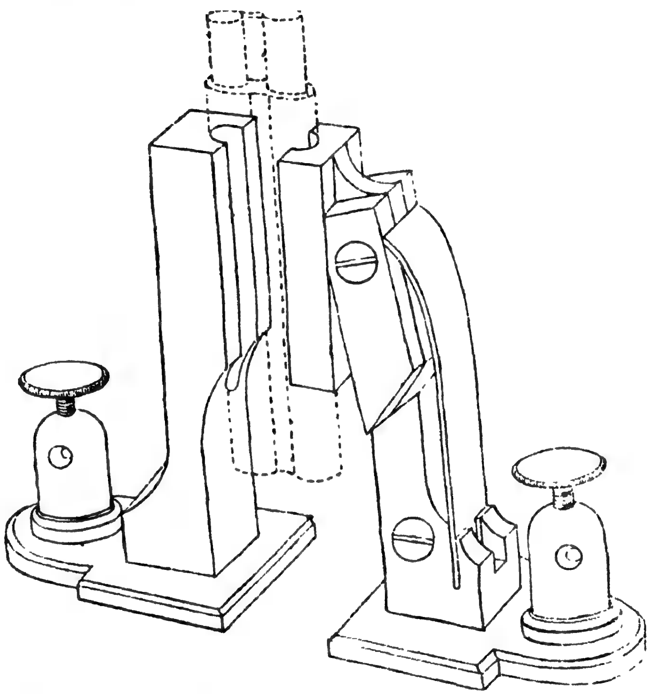
The commutator, Fig. 1177, combines two or more electro-magnets A, B, and C, with their respective armatures *a*, *b*, *c*, in such a manner that, when the connection to one of the carbons in the lamp is interrupted, the corresponding electro-magnet releases its armature, and this then serves to throw the current through the electro-magnet corresponding to the next carbon, causing it to light. The number of electro-magnets is one less than the number of carbons.

Each armature when not attracted forms contact with a pillar A′, B′, C′, respectively. Supposing there are four carbons, one of which only is to be alight at a time, the current passing first through the coils of an electro-magnet A, placed between two other electro-magnets B and C; the armature *a* of the middle magnet A being attracted, will be drawn away from a contact A′ connected to the coil on the top magnet C, and the wire connection from the middle magnet A to the coil of the bottom magnet B, will cause the armature *b* of this magnet to be attracted, and drawn away from the contact B′ connected with the binding screw 2 for the second carbon.

The coil on the bottom magnet B is connected to the terminal binding screw 1 for the first bottom carbon. If this carbon becomes inoperative, the armature *b* for the bottom magnet B will by its spring *b′* be pulled over against the contact B′ in connection with the terminal binding screw 2 connected with the second carbon, and no current will pass through the bottom or top

electro-magnet coils B and C respectively. When the second carbon becomes inoperative, the armature a of the middle magnet A is let go and comes against the contact A′. The armature c of the top magnet C is then attracted, and the current passes through the armature a of the middle magnet A′ through the coils of the top magnet C and to the terminal or binding screw 3 for the third carbon, and so on.

P. Jablochkoff's electric candle consists of two cylindrical carbon rods, about $\frac{3}{16}$ in. diameter, each weighing about 8 grains an inch. These rods, varying from $6\frac{1}{2}$ in. to 10 in. in length, are placed vertically side by side, with about $\frac{3}{16}$ in. space between them, which is filled with plaster of Paris. This combination constitutes a candle, and it is inserted in a holder, Fig. 1178, and there held merely by a spring clip. To complete the circuit and to start the lighting of the candle, there is laid horizontally, from top to top of the carbon rods, a small piece of graphite or lead from a drawing



pencil. When once lighted, combustion is maintained by fusion of the plaster of Paris, and the candle, if once extinguished, cannot be relighted. The fusion of the insulating material is found to absorb about 30 per cent. of the electric current. The relative consumption of carbon on this system is shown by the following table, where the first light is obtained from a constant current system, and the second from a candle;—

TABLE VII.

Light in Candles.	Length consumed in Inches an Hour.	Approximate Weight in Grains.	Grains of Carbon an Hour for Candle-power of Light.
705	3·15	20·3	0·106
760	3·0	7·5	0·060

But with a light of 1230 candle-power from a continuous current system, only ·062 grain of carbon for each candle-power of light has been consumed an hour, showing the advantages of the different systems respectively.

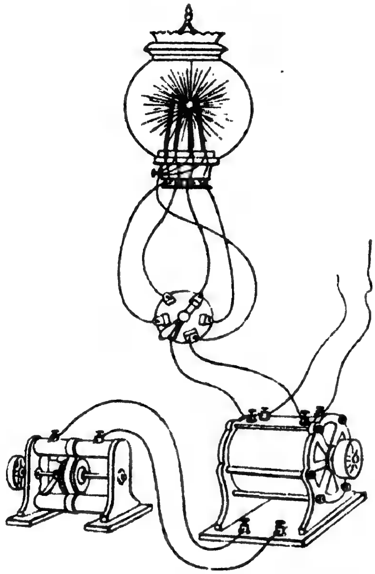
Fig. 1179 represents the arrangement of the lamps and machines upon the Jablochkoff-Gramme system, usually employed with the Jablochkoff candle. To effect the ignition of a fresh candle, an automatic arrangement has been devised, which consists of a pivoted bent lever pressing by a spring against the side of the candle. This lever at its other end makes contact with the connection of a second candle, when released by the consumption of the first.

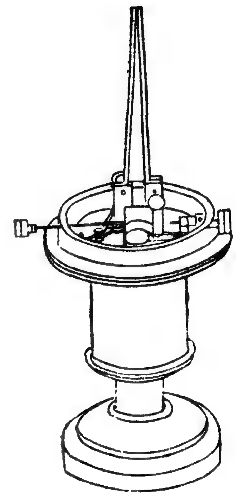
The objections to the Jablochkoff candle on the score of difficulty in relighting, and loss of current consumed in the fusion of the insulating material, lead De Meritens to place between the two carbon rods, but not in contact with them, a third rod, of about half the diameter, instead of the insulating substance. The electric arc plays from the outer carbons to the intermediate rod, which is con-

sumed. The arc thus divided has less probability of total extinction, and requires lower expenditure of power to produce, as it has less distance to leap.

Rapieff's candle lamp, Fig. 1180, is a return to mechanical aid. There is no insulating material between the carbon rods, and their distance apart is regulated by a screw. The holder of one of the carbons is connected to the armature of an electro-magnet concealed in the stand. When no current

1179.





is passing, the upper ends of the rods are brought into contact by a spring, attached to the armature of the movable carbon. When a current passes the armature is attracted, and the carbons are separated to the distance necessary to produce the arc. Upon interruption of the current the armature is released, and the circuit again completed.

H. Wilde's candle lamp is similar in principle to the preceding, but includes an automatic switch, which by means of a spring brings successively into play a series of lamps as the consumption of carbon regulates, the temporary cessation of current releasing a table upon which the lamps are fixed. This table revolves, and brings into contact, with the conductors, another lamp.

The production of the electric light by the incandescence of a badly-conducting substance, has been regarded by electricians as presenting the most simple and advantageous system. But there are difficulties attending the plan not apparent at first sight, and the chief is choice of the material to be raised to incandescence. Metals are subject, even platinum and iridium, to accidental fusion by sudden increase of current; carbon, although infusible, oxidizes when heated in contact with air, and has to be renewed. Means of removing the air, and maintaining an atmosphere free from oxygen, have not been carried out in practice. Platinized asbestos, finely divided oxides, plumbago mixed with kaolin, have been proposed, but these substances have not hitherto given satisfactory results, becoming brittle under the influence of the intense heat, or otherwise suffering change after short periods of use.

King, in 1845, first proposed the use of a carbon rod, which was supported between two blocks of carbon, in a glass vessel from which the air had been exhausted. Lodyguine, in 1873, re-introduced the system, diminishing the section of the carbon at the luminous point.

Konn's lamp contained two carbons, the second being brought into use when the first was consumed, by the simple expedient that consumption of the first allowed a trip hammer to fall into contact with the second.

In Bouliguine's incandescent lamp, the carbon rod was forced upwards by a counterweight into the clip-jaws of an upper holder. When the current ceased, an electro-magnet released these jaws, allowing the broken carbon to fall out, and its place to be supplied with a new length of the rod, under the upward action of the counterweight.

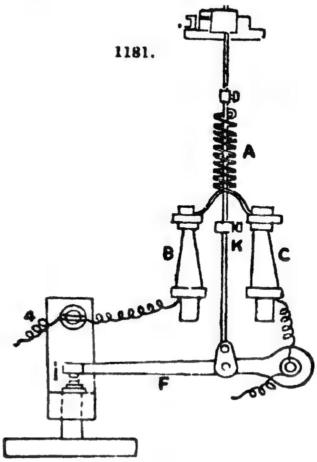
None of these lamps are now in practical use; but a modification of the system has been adopted in the Sawyer-Man burner in use in America. In this burner the incandescent portion consists of hard wood-charcoal quenched in oil, by which a very dense steel-like carbon is obtained, through the condensation of the carbonized oil in the pores of the heated charcoal.

Fig. 1181 is of T. A. Edison's incandescent lamp, in which fusion of the platinum coil, used as the bad conductor, is prevented, by shunting the current when too intense, by the expansion of the coil itself, or by its radiating effect. The spiral A is connected to the supports B and C, and is surrounded by a glass cylinder. K is an expansion bar, fixed firmly above, and attached also to a lever F, which can connect electrically the two conducting supports B C. The rod K will expand in proportion to the heat of the coil, and, if the heat becomes too high, injury to the coil is prevented

by the expansion of the rod K causing the lever F to close the circuit at I, and short circuit the current from the coil A. Immediately the rod K cools, the short circuit is withdrawn.

Whether the use of carbon or of platinum is the more economical has yet to be determined. Ayrton has shown that light should be maintained in a carbon rod by a minimum electro-motive force of about half a Daniell's cell, whilst one-third cell only is required for platinum. But the same quantity of caloric raises the temperature of a small bar of carbon, to a degree nearly twice that attained by a platinum wire of the same dimensions. The resistance of the carbon is about 250 times that of the metal, so that a carbon rod may be fifteen times thicker than a platinum rod to give the same result.

1181.



The maximum light attainable in practice in any system of incandescent burners appears to be of 250 candle-power. Beyond the temperature necessary to produce this amount of light, the fusion of the siliceous impurities in the carbon affords much difficulty. Economically considered, when the light passes that of 100 candles, the system of incandescence rapidly becomes disadvantageous, as compared with that of the arc, whilst the use of the arc becomes cheaper as the light-centre is more intense.

Ayrton has also remarked, that the insulating material in the Jablochkoff electric candle owes its imperfect success to the fact, that when it became heated, the resisting power was greatly diminished, so that there was a great loss of current through leakage from one carbon to the other. Wilde shows that the employment of this insulating substance is needless, for when he used a Jablochkoff candle with only air between the carbons, the electric current passed from carbon to carbon, at the top, and not along the whole length; and further, if the arc were started, by means of a wire placed and withdrawn, at any other part of the parallel carbons than at the top, it immediately proceeded to the top, at which place alone it continued to shine.

Wilde attributed this curious effect to the convective action of the heated air, considering, in fact, that the air was blown up to the top of the carbons, very much as a lighted piece of paper is blown up a chimney. Ayrton has shown, that while convection of the air greatly assisted the action, the fact that the arc would travel downwards if the lamp were inverted and lighted at the now upper part of the carbons, near the metal carbon holders, proved that the cause of the motion was not only quite distinct from air convection, but was sufficiently strong to overcome such convection, and that the explanation was, that this motion was caused by the repulsive action between the currents in the carbons, and that constituting the arc itself, in accordance with Ampère's law, concerning the action of a current on another at right angles to it.

With considerable experience in the practical manipulation of most of the systems for electric lighting, P. Higgs has found that some systems presented considerable, and that others of more delicacy of adjustment, necessary to practical employment, gave insuperable, difficulties. These difficulties arise chiefly from three causes: that the carbons are not homogeneous, the current inconstant from variations in the resistance of the circuit, and generally from the want of promptness in the mechanism of the lamp to respond to the variations so caused. Most of these electrical apparatus have been devised either with too broad or imperfect views, or with only special application. In the case of carbon holders carrying 7 or 8 in. of carbon to be consumed, the resistance of this amount of carbon, if the material is not of the highest quality, is likely to exceed that of the arc and lamp itself; and this resistance, constantly varying, has to be compensated for by the mechanism of the lamp. This imperfection has been avoided by Rapieff, Werdermann, and Lontin. Some inventors have recognized it, and have proposed, as a remedy, to electrotype the carbon rods with a conducting metal; but the practical electro-metallurgist is cognisant of the difficulty of obtaining regularity in such deposits of metal, and the expense of the coating is, besides, to be taken into account. In each case the long lengths of carbon become heated, and with coppered carbons, the mass of metal is insufficient to carry away the heat generated by the passage of the current.

The first aim of the electrician who has to maintain an efficient and steady light is, undoubtedly, to obtain as constant a current as it is possible with either a battery or an electric machine. Battery currents vary, as a rule, very gradually; currents produced by mechanical motion are subject to the irregularities of that motion. The slip of belting, the beats due to want of balance in the flywheel, are represented in the electric current with too much fidelity for the comfort of the electric-light engineer. But with care these causes of irregularity can be avoided, and the needle of even a delicate galvanometer, interposed in the circuit of a well-set machine, driven by a steady motor, will remain fixed at a degree of deflection representing the current strength.

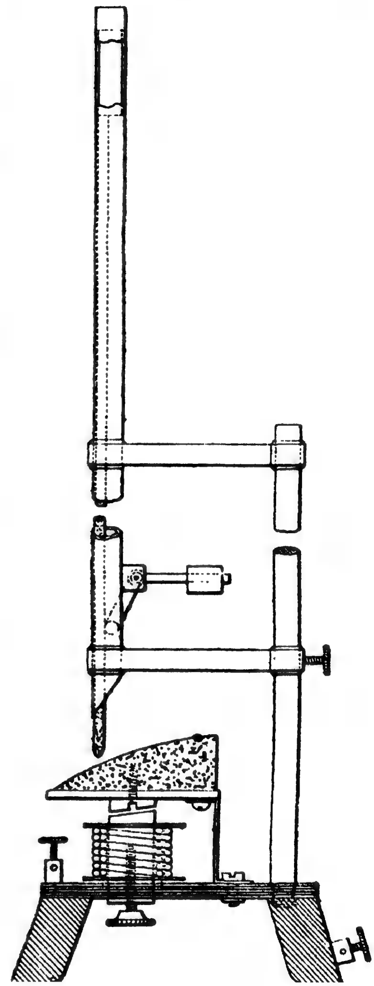
But this steadiness vanishes immediately the electric lamp is introduced into the circuit, so far as the light is concerned. This occurs partly because the lamp is, as regards the light it emits, a much more delicate current measurer than the galvanometer. The light power from the carbons of an electric lamp depends not directly upon the current strength, but increases or decreases far more than proportionally.

The heat produced by the current varies as the square of the current strength, and the light varies in some such ratio as regards the heat. Thus, a variation in current intensity, measured by the number 2, may be considered in illustration as causing a variation of 16 in the light intensity. It is, therefore, needful to avoid causes of variation in the lamp, for these, it is evident, will have

similar effect upon the light intensity to those arising from the machine. Indeed, variations introduced by the lamp cause variations to occur from the machine, unless the latter be extremely well governed.

A decrease of resistance in the circuit causes more work to be thrown upon the motor, and conversely. If the motor, in consequence, momentarily slackens or increases speed, there must elapse several moments before the same conditions, as existed before the disturbances, are again established, and the largest of these variations are certainly visible as variations in the light. That most of these variations are due to reaction from variations in the lamp itself, is proved by the superior steadiness of the light produced on the principle of incandescence alone. This fact has caused many inventors to overlook the cost of the light produced merely by incandescence, and to avoid in their lamps the use of the voltaic arc, with what appears to be its necessary attendant irregularity.

1182.



Higgs's lamp, illustrated in Fig. 1182, is an attempt to avoid as much as possible causes of irregularity, and at the same time to produce a light with small expenditure of power. It utilizes the principles of incandescence, of the arc, and of the extra spark. It consists of an electro-magnet, in face of which is an armature mounted on a spring. The armature carries a block of carbon, iron, or compounded material as a negative electrode, which is not consumed, or is consumed with extreme slowness. The positive electrode is a carbon rod, carried in a tube and falling with a certain friction imposed by a weighted lever, which admits carbon rods of several sizes to be introduced, as may be best suited to the strength of the current. The falling of the carbon can be aided by a weight or spring. The distance of the bottom of the tube from the negative electrode can be adjusted, and limits the length of carbon rod rendered incandescent by the current. When the current passes, through the positive carbon coming into contact with the negative electrode, the armature is attracted, and the voltaic arc and extra spark appear; the current, weakened by this action, fails to keep the armature attracted, and in this manner constant vibration of the negative electrode is established. This vibration is imperceptible to the eye. Its advantage, beyond that of producing the extra spark, which spark itself appears to afford aid in maintaining the voltaic arc, is that the armature has no dead point, and floats, as it were, above the electro-magnet, in a condition to respond promptly to magnetic effects caused by larger increments or decrements of current strength.

It is preferable to place an insulated spring between the end of the friction-lever and the armature, instead of the weight on the end of the lever; the carbon rod is then allowed to fall freely when required, and as released by the rising of the armature.

With four ordinary Bunsen elements, sufficient light has been obtained to illuminate a shop 60 ft. by 40 ft.; and upon the single circuit of a dynamo-electric machine absorbing 2½ horse-power, four lights, of about 400 candle-power each, have been obtained with sufficient steadiness to read by with comfort.

Telephones.—Probably the earliest instrument devised for transmitting sound by the agency of electricity was the musical telephone invented by P. Reis, in 1860, who afterwards introduced the improved form, Fig. 1183. The instrument is in two parts, a transmitter A, and a receiving instrument R. The transmitter has a membrane S, stretched over a circular hole at the top of a cubical box A, in front of which, and opening into it, is a mouthpiece M. The membrane vibrating in unison with the impulses it receives from musical sounds played near it, transforms those impulses into a series of electrical currents, by a simple make-and-break arrangement *g*, and these currents acting on the receiving instrument, which may be hundreds of miles distant, reproduce the corresponding notes, so that a tune played at one station can be distinctly heard at the other.

Reis's receiving instrument is founded upon the phenomenon discovered by Page in 1837, that a distinct sound accompanies the demagnetization of an iron bar, placed in an electro-magnetic helix. It consists of a soft iron bar about the size of a knitting needle, surrounded by a helix of wire, which forms part of a voltaic circuit, including the battery B, with the transmitting instrument; and, for intensifying the effect, both instruments are provided with sounding-boards.

When notes are sounded into the mouthpiece, the membrane is thrown into vibration, and a platinum plate, attached to its centre, makes and breaks contact with a contact screw, and in so doing completes and interrupts an electric current which traverses the receiving instrument, the bar of which becomes magnetized and demagnetized at each complete vibration. By this means, the note

sounded into the transmitter is reproduced by the receiver, the action of the two instruments being isochronous.

Varley devised a musical telephone, using a tuning-fork, in conjunction with an electrical condenser, to transmit vibratory currents to a distant station, and there to reproduce musical sounds.

P. Lacour has constructed a remarkable instrument, termed a phonic wheel, which is susceptible of many important applications. This wheel, which is in reality a small electro-magnetic machine, is so arranged that, when set in motion by electric vibrations produced by the action of an electro-diapason or telephone, it obtains a perfectly uniform rotary movement, which is not interfered with by external mechanical reaction not sufficiently powerful to arrest it.

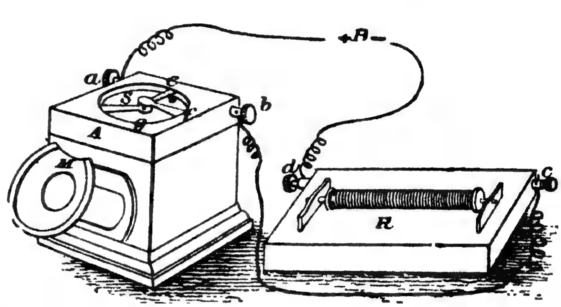
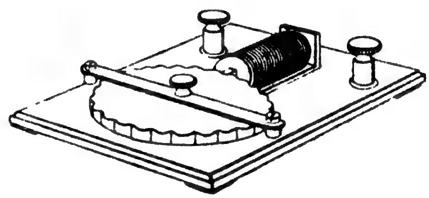
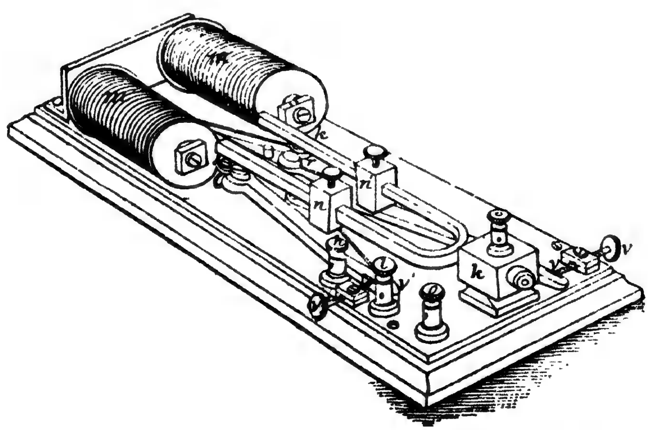


Fig. 1184 is of the phonic wheel, consisting of a toothed wheel of soft iron, movable about its axis, facing which is placed a straight electro-magnet, so that one of its poles, when excited, reacts upon the teeth without contact, similar to the action of electro-magnetic machines having a direct movement of rotation. If a series of currents having equal duration and intervals, as transmitted by an electro-diapason, be sent through the electro-magnet, the reaction of the latter upon the teeth results in a series of attractive effects, which can maintain an initial movement communicated to the wheel, and rendering this perfectly uniform, when the rapidity of rotation is such that the wheel traverses in each period occupied by a current, a space equal to the distance between the consecutive teeth. Currents thus transmitted are distributed by an electro-diapason or telephone, Fig. 1185, which consists of a tuning-fork placed horizontally, with its stem projecting through a wooden stand *k*.



The position obtained at each movement by this wheel, is such a function of the times as can be designated as mobile equilibrium. The reality of its existence can be proved by slightly urging or retarding the wheel in its motion. If the movement be opposed, the attraction will accelerate it



more than retard it. If the velocity of the wheel be augmented, the retarding action will be greater than the accelerating action. Thus a slight deviation communicated to the wheel in either direction is compensated and rendered valueless, by reason of the compensating attractions; and the mobile equilibrium constitutes therefore a condition of stable equilibrium.

Lacour states, if an electro-magnetic diapason is caused to react upon a current traversing the electro-magnet of a phonic wheel, this wheel, when once it has obtained a movement which causes one tooth of the wheel to pass in front of the electro-magnetic pole during each electric wave, will preserve a position of uniform movement, which can be termed a regulated movement, analogous to that of repose of the wheel when one particular tooth is attracted in the direction of the pole.

If the phonic wheel be travelling with a regulated motion, and an external force tends to slightly deviate it from the position of mobile equilibrium, the phono-electric current causes it to return to this position. But if this force remains constant, the wheel, still preserving its velocity of rotation, will find another position of mobile equilibrium, which will depend upon the force and its direction in reference to that of the rotation. It is this constancy in the velocity of the phonic wheel, despite external forces, that permits of its application to chronographs and to apparatus in which a synchronous motion is necessary. These forces must not, of course, exceed a certain limit. If the external force exceed the limiting value, the mobile equilibrium is destroyed, and the velocity of the wheel accelerated or retarded according to the direction of this external force. The maximum mechanical force measured is 1 kilogrammetre, = 7·23 foot-pounds, a minute.

There are other velocities at which the phonic wheel may be, and may maintain itself in a position of mobile equilibrium. If the wheel turns with a velocity only half that which corresponds with the regulated movement, so that one tooth passes the pole for every two waves of the phono-electric current, the relation of each tooth to one of the two waves of the phono-electric current, will be exactly the same as that when the wheel is regarded as in regulated movement, and this wave maintains the stability of the mobile equilibrium, which might be maintained by the other wave, if the magnetic pole and the teeth of the wheel presented a sharp angle.

The phonic wheel can maintain itself in rotation with velocities which are the nearest sub-multiples, or multiples, of the velocity of the regulated movement of rotation. At all velocities the phonic wheel turns equally well in either direction.

The phonic wheel is susceptible of a uniform velocity only between certain limits, by reason of the frictions and external actions to which it is subject. The limit depends upon the construction of the wheel, and its extent is small, if any electrical conductors capable of influencing the wheel by induction are in its locality. Lacour has experimented with some phonic wheels, which work only with a velocity determined by 100 waves a second, while others work only under the influence of a phono-electric current giving 600 waves, in the same space of time.

The angular velocity of the phonic wheel depends, not only upon the acuteness of the sound emitted by the vibrating apparatus, but upon the number of teeth. Lacour has tried wheels having 18, 20, 24, 30, 36, 60, and 100 teeth, and obtained with all a regulated movement under the influence of a rather acute phono-electric current, without being able to decide which number produced the movement with the greater certainty. Wheels having a small number of teeth are more difficult to set in motion, having a greater velocity of rotation. Lacour shows, with regard to lineal velocity, that a phonic wheel with eighteen teeth, in which the distance between the median lines of two adjacent teeth was 20 millimetres, can turn with an interrupted phono-electric current giving 245 waves a second, which gives, as the lineal velocity, 245 × 21 mm. = 5m. 145, or about 20 kilometres an hour. The phonic wheel is of great value when a high constant velocity is required. It is applicable as a counter in measuring the velocity of other movements, it being simply requisite for this purpose, to cause the wheel to act synchronously with these movements, and as it is provided with a registering apparatus, the velocity of the movements can be easily determined. If the velocity of a wheel in a machine is required to be determined, a toothed wheel is fixed to the axis, having the same number of teeth as the phonic wheel, and the former is used as an interruptor, the phonic wheel moving synchronously with it.

If the velocity to be measured is too great to allow of its corresponding with that of the phonic wheel, a groove can be made in the axis, allowing of a contact at each revolution, which will be denoted by a single tooth of the phonic wheel.

When used as a counter, the phonic wheel moves equally, thus offering at a distance, if necessary, a correct representation of the movements of the machine; it never misses, as it is impossible that a single tooth of the wheel should be passed over without the wheel stopping altogether, and it can count with greater rapidity than any other rapid counter.

One of the most important applications of the phonic wheel is to telegraphic systems requiring perfectly synchronous movements, such as Hughes' printing instruments and Meyer and Baudot's multiple telegraphs. For this purpose a support carries on its upper portion an ivory wheel, in the surface of which are sunk sixty equidistant and insulated metallic plates. These plates are connected, by means of conducting wires, to sixty binding screws fixed to the base of the apparatus, where they are arranged in two circles at different levels, so that the plates communicate alternately with an upper and a lower binding screw. These plates have a smooth surface, on which slides a revolving friction piece, mounted on the axis of a phonic wheel with thirty teeth, which is placed beneath the brass disc concentrically with it. To the left are seen the poles of the acting electro-magnet, which traverse the support of the apparatus, and are brought into proximity with the phonic wheel. At the sending station the diapason transmits phono-electric currents to the electro-magnet of the phonic wheel, and the revolving wheel, touching in succession all the plates, sends alternately, through the line wire, the currents of two batteries, which being connected with the even and odd plates by poles of opposite sign, furnish charges alternately negative and positive.

At the arrival station, these currents, after having traversed the electro-magnet, and set in action the electro-magnetic system of the phonic wheel, are conducted to the support of the latter and to the friction piece, which transmits them to the plates, and causes them to pass to earth. In traversing the electro-magnet, these phono-electric currents maintain in synchronous and continuous vibration the diapason, which vibrates under the same conditions as the diapason at the sending station, and which causes the wheel at the arrival station to turn synchronously with the other wheel at the sending station, and the friction piece passes over the plates at the arrival station, exactly at the same moment as the other friction piece passes over the corresponding plates at the sending station.

The negative and positive poles may be separated, and made to produce the effect of distinct currents in opposite directions. If the odd plates be placed in contact with a galvanometer, before the circuit is put to earth, the series of negative waves will produce a continuous deflection in a

determinate direction, opposed to that of the deflection produced by similarly connecting the even plates to earth through the instrument.

By acting upon the electro-magnet of the phonic wheel at the arrival station, it is possible to obtain a maximum deviation, which will then indicate that each positive or negative wave passes wholly or mainly through the even or odd plates. This constitutes a means of regulating the synchronism of the two apparatus, and also one for obtaining the maximum effects of the current.

To bring the homologous plates into connection when the apparatus is adjusted, a commutator may be employed at the arrival station, furnished with thirty conductors, which are in communication on the one hand with the thirty even plates of the phonic wheel, and on the other hand with the thirty telegraphic instruments which it is intended to work; and it is brought successively on to the different contacts, until the currents sent by one of the transmitting instruments arrives at the receiving instrument with which it is intended to correspond. The commutator, under these conditions, will produce the same effect as if the friction piece had been taken by hand to the plate with that touched by the friction piece at the first station, at the same moment. It is possible to transmit from the sending station, through the intermediation of thirty instruments, signals which will be reproduced by the same number of instruments at the arrival station; and each of these instruments can transmit as many signals a second, as the number of revolutions made by the phonic wheel in the same space of time.

This instrument is applicable to scientific research, insomuch that if it be necessary to study any phenomenon, manifesting itself at a given moment of the period of transmission of an electric wave, as, for instance, the force of a phonic-electric current at different moments of its emission, the phonic wheel can supply the requisite indications. It is simply necessary to arrange an insulated contact piece, so that the teeth of the phonic wheel may touch it at the moment when the phenomenon is to be observed. By making the current pass through this interrupting system, a derived circuit is obtained, which can easily be studied, and which corresponds to that phase of the wave which has to be considered.

On account of its uniformity of motion, the phonic wheel can be employed to measure, or represent graphically, the velocity of rotation at each moment of any apparatus or machine.

Lacour shows that there are various methods of proceeding; one of the simplest is, the axis of a phonic wheel maintained in regulated movement by means of a diapason carries a thin black disc, perforated with equal and equidistant holes, arranged in the form of several concentric circles, ten, for instance, of which that which is nearest the centre contains five holes, the next ten holes, and so on, up to the tenth circle, which will contain fifty holes. Upon looking down upon a white surface through this revolving disc, the circles appear as circular zones of a grey colour, and concentric.

The machine of which the velocity is to be measured produces the rotation of a cylinder, which is painted with black and white stripes, of equal breadth, parallel to its axis. This cylinder, which appears of a grey colour, is situated beneath the disc described. If the machine possesses a velocity capable of making the cylinder advance by thirty-five stripes, for instance, for every rotation of the phonic wheel, the seventh zone of the disc will show the black and grey bands motionless. If the velocity of the cylinder augment slightly, the bands will be seen to move in the direction of the rotation of the cylinder, and the greater revolution of the latter the more rapid will seem to be this motion of the bands. If the velocity continue to augment in the eighth zone, other bands will appear, which, commencing with a rapid motion in the direction opposite to that of the former bands, gradually slacken, as the bands of the seventh zone move faster, and finally remain at rest. The machine will then have a velocity capable of making the cylinder advance to the extent of forty black stripes, for every rotation of the phonic wheel.

The application of the apparatus is very simple. The zone which exhibits the stationary bands is at once perceived, and the velocity of the cylinder is proportionate to the corresponding number which is inscribed upon a fixed scale, with which the apparatus is supplied. Should the zones show bands apparently moving in contrary directions, the velocity of the cylinder is somewhere between those corresponding to these two zones. This method allows of direct observation at any moment of the velocity of the cylinder, and of any variations of this velocity. Other arrangements of the apparatus allow of numerous researches on the phenomena of induction, static charges, the velocity of electricity, and the determination of geographical longitude.

One of the most original of musical telephones is that invented by Elisha Gray. It is founded on a phenomenon first observed by Gray, that when a dry, thin, metallic surface, connected to one end of the secondary current of an induction coil, is rubbed by the hand, while the operator is holding the other end of the secondary wire, a sound is emitted by the hand at the point of contact with the metal, which sound has the same pitch and quality as that given out by the contact-breaker of the coil. Raising or lowering the speed of vibration of this contact-breaker, immediately raises or lowers the pitch of the note. From this Gray was led to construct a keyboard containing an octave of keys, each of which on being depressed started into vibration a reed, which, while giving out the note corresponding to its key, transmitted to the induction coil at the receiving end an intermittent current of electricity. With this transmitting instrument the finger of an assistant at the other end, was caused to reproduce whatever tunes were played on the keyboard.

Fig. 1186 is of Gray's receiving telephone; in using this instrument the thin metal chamber is connected through the stand to one terminal of an induction coil, in circuit with the musical sound transmitted at the distant station, and the operator, taking hold of a wire *a* connected to the other terminal, presses his fingers on the metal surface while he turns the handle with the other hand. With this simple apparatus every tune played at the transmitting end is reproduced, and the more rapid the rotation the louder the sound, no sound whatever being emitted when the rotation is suspended.

Graham Bell's articulating telephone was introduced in 1876, and is largely in use. In its early stage the transmitting instrument consisted of a horizontal electro-magnet, in front of which and perpendicular to the plane of its axis is fixed a brass ring; over this a membrane is stretched, tightened by means of screws; to the centre of this membrane is attached a small oblong piece of

iron, situated immediately in front of, and almost in contact with, the poles of the electro-magnet; binding screws on the stand of the instrument are used to place the coils in circuit with the receiving instrument. This was formed of a thick tube of soft iron, enclosing a vertical bar electro-magnet, rather shorter in length than itself, the two being so connected at the lower end that, while the central bar under the influence of the current assumed north magnetic polarity, the tube surrounding it became by induction a south pole of annular form. To the top of this tube was fastened, by a small screw, an iron disc about the thickness of cartridge paper, and this disc, under the influence of a voltaic current, was held firmly down by the annular pole, its centre being in front of the shorter central pole. It thus constitutes a diaphragm held by its edge by magnetic attraction, its centre being presented to the north pole of a magnet as in the later receiver. The action of the instrument may be explained as follows: When sound waves are projected against the membrane of the transmitting instrument, the iron strip attached to it is set in motion in the manner described, and plays to and fro in front of the poles of the electro-magnet, in obedience to the impulses of the sonorous vibrations; by this action a series of variations in the strength of the currents are induced, proportional to and synchronous with the variations in the movement of the membranes, and these variations are transmitted by the connecting wire to the receiving instrument, and are reproduced there and converted into sonorous vibrations by means of the diaphragm armature of the receiving instrument.

1186.

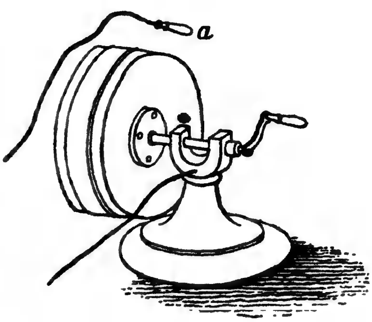
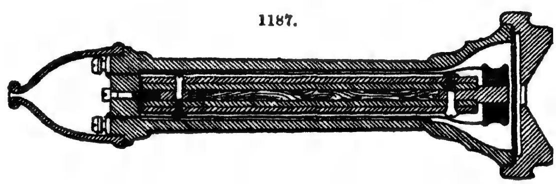


Fig. 1187 is a section of a recent form of this instrument, in which several improvements have been introduced. The most important of these is the compound nature of the magnet, which is composed of four bars of steel of flat rectangular section placed in two pairs, which are separated by a similar bar of soft wood, and united at their upper extremity to a soft iron pole-piece, which is surrounded by the coil of insulated wire in circuit with the distant station. The case is constructed of ebonite, and the mouthpiece screws down over the body of the instrument, so as firmly to hold the edge of the ferrotype diaphragm between itself and the rest of the case.

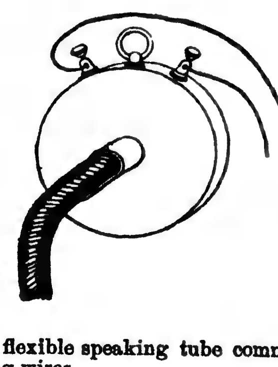
1187.



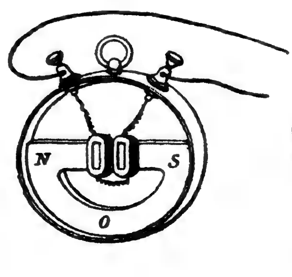
In the Gower telephone, Figs. 1188 to 1191, the magnet *o* describes a segment of a circle, the narrow, oblong poles N S, which are brought close together in the middle of the chord, being wound with flat coils of fine wire, each having a resistance of 60 ohms. The magnet is composed of French steel, magnetized by a process that enables it to support ten times its own weight. The coils approximate very closely, and the flat coils exert magnetic effect upon the diaphragm. The diaphragm consists of a soft iron plate 3⅝ in. in diameter. A brass ring holds it down upon the ledge of the box, which supports it.

The box is of brass, on account of the greater resonance of metal compared to that of wood, and its uniformity of expansion and contraction. Fig. 1188 is of the back of the cover of the box,

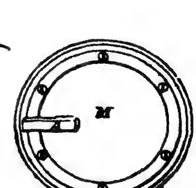
1188.



1189.



1190.



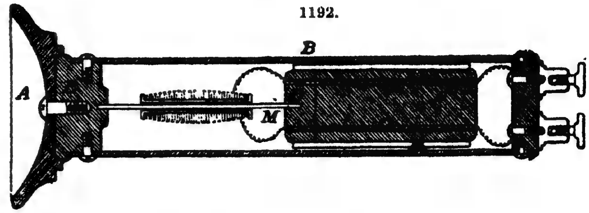
1191.

having a flexible speaking tube communicating with the diaphragm, and binding screws for the connecting wires.

The call of the Gower telephone consists of a harmonium or concertina reed, Figs. 1190, 1191, fixed to the under side of the diaphragm M, opposite a narrow slit in the latter. Air sent through the speaking tube passes through this aperture in the diaphragm, and agitates the reed, which sounds like a miniature trumpet or horn, and being placed within the magnetic field transmits its note over the telephone wire to the distant station, where it can be distinctly heard. Fig. 1190 shows the position the call occupies in the instrument.

Fig. 1192 is of the Ader telephone. An iron wire, or strongly magnetized needle M is soldered at each end to a mass of copper E and D, and surrounded by a bobbin or coil of insulated wire. The copper mass D is soldered to a larger mass of lead C, which is perforated longitudinally at O O, to allow the ends of the coil to be brought to the binding screws at F, by which the telephone is connected in circuit. The metal mass D C must be phonetically insulated from the mass E, to prevent confusion of vibrations, consequently D C is encased in a sheet of indiarubber H. The ear-piece A is fitted to the instrument, and on listening, while the vibratory currents flow in the coil, the sounds are audible.

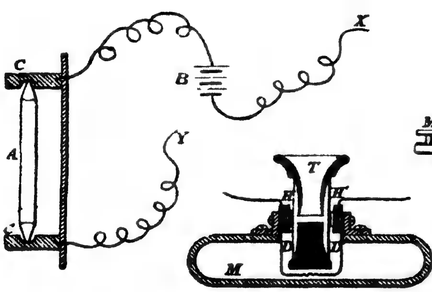
1192.



The general form of T. A. Edison's first telephone somewhat resembles the hand-telephone of Bell, although all analogy ends at this point. Through the middle of the body of the case passes a stem, terminating at its upper extremity in a shallow cylindrical box or cup; this stem can be raised or lowered by means of the adjusting screw at the lower end of the case; the cup referred to contains a thin platinum disc, and superimposed upon it a button of carbon, with a second disc of platinum. This series is held in place by an annular cover screwed down on the box, and a thin diaphragm is employed, being held in place by the mouthpiece, which is screwed down upon it, a small piece of rubber-tube being introduced between the diaphragm and the upper platinum disc, in such a manner as to exert a constant, but light, pressure upon the latter. The upper and lower discs of platinum are connected respectively to the two terminal screws, by which the instrument is placed in circuit with the battery and receiving instrument at the other end of the line. The action of this instrument depends upon the varying resistance of the carbon disc, due to variations of pressure exerted upon it by the movement of the diaphragm, under the influence of sonorous vibrations impinging upon it.

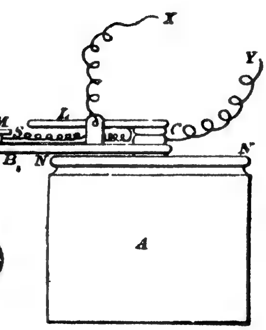
The latest form of Edison's carbon transmitter, Fig. 1195, has a carbon disc contained within an ebonite ring, screwed to the metallic portion of the frame forming one of the connections of the circuit, and the carbon button A rests upon this metallic surface. The other face of the button is covered with a disc of platinum foil, connected to an insulated terminal, and forming the other

1193.

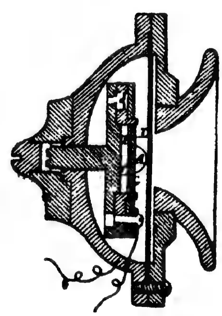


1196.

1194.



1195.



circuit connection; this foil is cemented to a disc of glass, in the centre of which is placed an aluminium stud, that bears against the diaphragm D of the instrument. This is an exceedingly simple and compact form of telephone.

A novel form of Edison's telephone, Fig. 1197, includes a transmitting telephone, a call bell, and a receiving diaphragm. The connecting wires L show the connections between the transmitter and the binding screws to the battery.

F F is a cast-iron standard, into which one end of the spring S is fixed. The pressure of this spring is regulated by the screw B. The main axle is supported by the boss in F F, and is connected to the handle H, by the train of wheels W W′. This handle can be rotated by hand or automatically. Upon the main axle is placed a chemically prepared cylinder of chalk K. The cylinder is a composition of chalk and potassium hydrate, with a small quantity of acetate of mercury, moulded round a brass reel, lined with platinum on the parts in contact with the mixture, which is kept moistened.

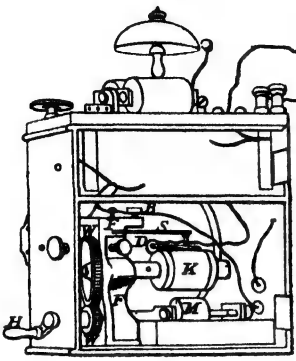
A metallic strip is arranged upon, and at right angles to the cylinder, fastened to the diaphragm at D. The pressure of the metallic strip is regulated by the screw S. The diaphragm, Fig. 1197, consists of a mica plate 4 in. in diameter. A damping roller M rests in a trough of water and is arranged to be raised against the chalk cylinder when necessary.

The action of this apparatus is as follows;—Between the metallic strip resting on the chalk cylinder and the chalk, there is a certain amount of friction, and if the cylinder be caused to rotate away from the diaphragm, this friction tends to draw the diaphragm towards the cylinder. The amount of movement given to the mica plate, depends upon the friction between the cylinder and metal, and the friction rises and falls with the quantity of current passing, the greater the current

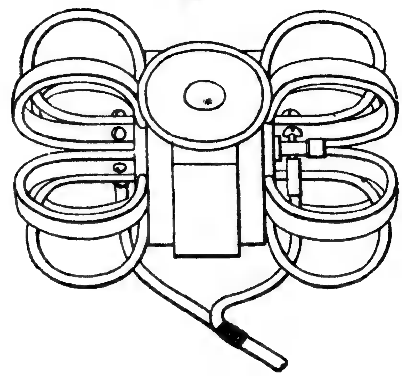
the less the friction, and conversely. By this means the fluctuations of the current produced in the carbon transmitter are faithfully reproduced as sound in the telephone.

The crown telephone, devised by G. M. Phelps, has been used with excellent results in combination with the Edison carbon transmitter. It consists of an ordinary combination of diaphragm, bar magnet and coil, but, in addition, there is a group of six permanent magnets, bent into a

1197.



1198.

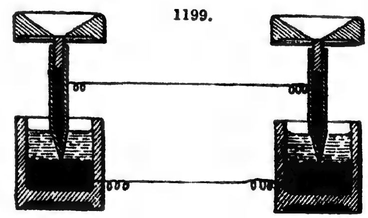


circular form, and having their similar poles joined up the central bar carrying the coil. The other ends of these magnets are attached to the edge of the diaphragm. The double crown instrument, Fig. 1198, is a duplication of the radial group of magnets described, a pair of coils also being introduced. These coils are so connected that the currents generated by the vibrations of the discs are mutually strengthened.

Another form of the Phelps telephone, Fig. 1196, includes a permanent bar magnet, bent so that the poles are brought near to each other. Attached to brackets on the poles of this magnet are two coils, opposite which are two diaphragms H, and between them is the central mouthpiece T opening into a chamber M, in which the pulsations of the air in talking, act upon the diaphragm through lateral openings. The coils are connected together, so that the currents generated by the vibrations of the diaphragm are in the same direction when united, and are consequently much stronger than when only one coil is employed. A similar instrument receives the messages at the other end of the line. There is another form of Phelps' instrument, which consists of a mouthpiece placed at the upper part of an oval ebonite case, containing a bent magnet connected to the bar carrying the coil behind the diaphragm, the other pole being attached to the periphery of the diaphragm, in the same manner as are the bar magnets in the crown telephone.

In Breguet's telephone, Fig. 1199, the transmitter and receiver are alike, and consist of a glass vessel containing mercury, over which floats some acidulated water. The pointed glass tube dipping into the vessel also contains mercury. These two vessels are connected, and over the top of each tube is a mouthpiece and diaphragm. On speaking above the tube of the transmitter, the vibrations are transmitted through the mercury, and contact is made with the acidulated water by means of the small opening left in the tube. The vibratory movements of the mercury by this means generate electro-capillary currents, which flow through to the receiving instrument, and reproduce the conditions which generate them, thus giving out the sounds spoken at the other end.

1199.



The sounds that are heard in a telephone are produced by the vibration of the metallic plate or diaphragm, which is set in motion by the variation of magnetic intensity in the permanent magnet placed behind it, which variation of magnetic intensity is produced by a current of electricity traversing the coils, this itself constantly varying in intensity according to the motion of the diaphragm at the distant station. It is not the current alone that produces these results, but the undulatory or constantly varying nature of that current. If at the distant station a single cell of a voltaic battery be substituted for the telephone, there will be heard in the receiving instrument a loud tick whenever the circuit is either made or broken, and if this be repeated with high and uniform velocity, as would be effected by using a tuning-fork as a contact-breaker, a musical note will be heard in the telephone.

If instead of breaking and making contact between a battery and a telephone, the resistance of the circuit or of the battery be suddenly changed, a sound is produced in the telephone more prolonged and more variable. It is this variation of resistance, producing a variation of the current, that led to the invention of the microphone by Hughes, Fig. 1193.

It consists of a small pencil of gas carbon A, such as is used in the electric lamp, pointed at each end, and lightly supported in a vertical position between two little cups, scooped out of the surface of small carbon blocks C C, which are attached to a thin sounding-board secured to a more solid base board. The blocks C C are connected by the wires X and Y, to the battery and line-wire leading to the telephone. This simple apparatus, rough as it is, is a most delicate instrument.

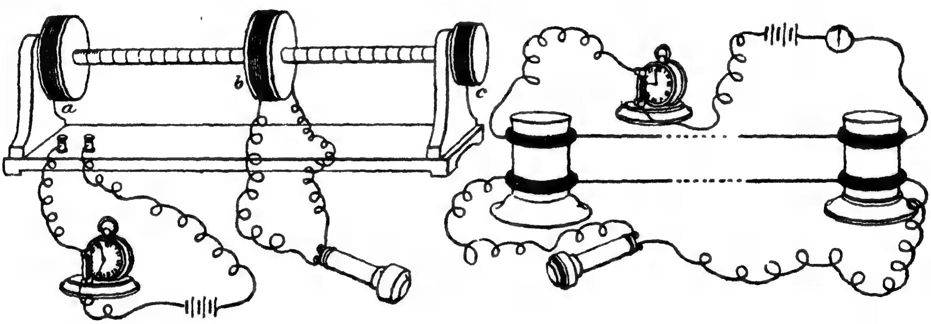
Not only is articulate speech taken up by it, and transmitted by it to a distant station with great power and distinctness, but it detects and converts into loud noises the minutest possible vibrations. The slightest stroke or the lightest touch, given to the base board, is sufficient to produce a loud grating noise in the telephone.

Another of Hughes's telephones is that illustrated on page 584, where Fig. 1194 is an elevation of the instrument. A is a small hollow cylinder of tin plate, closed at one end by the membrane N N of parchment, stretched over it like the head of a drum. To the centre of the membrane is attached a small block of pine, which carries the slip B, also of the same material, the block being of sufficient thickness to cause the farther end of the slip to be clear of the edge of the drum, so that the whole of the rest of the apparatus is supported solely by the centre of the membrane. Upon the slip of pine is fastened one of Hughes's articulating microphones, having a lever of brass L, pivoted at its centre of gravity between two supports, and carrying at one end a small slab of prepared pine charcoal C, which is maintained by the spiral spring S, at a constant pressure against a similar slab of charcoal below it, the latter being attached to the slip of pine. The degree of ... may be regulated by turning the milled head M, whereby

at C, Fig. 1194, are, under the influence of an
f mechanical vibration,

or conducting aural investigation with absolute
such an instrument. It is represented

1200.



by the accompanying Fig. 1200, and consists of a small bed-plate with a bracket at each end to carry a horizontal rod 200 millimetres in length, and of the section shown. At one end of this rod is fixed a bobbin *a*, with 100 metres of insulated wire wound upon it, and at the other is a similar but smaller bobbin *c*, upon which is wound about 1 metre of insulated wire. These coils are so connected together as to have opposite, but necessarily inductive, influences upon *b*. They are placed in circuit, with a battery, a galvanometer, and a clock-microphone. Sliding on the rod is the third bobbin *b*, carrying 100 metres of wire, in every respect similar to the bobbin *a*, and having a telephone in circuit with it. Induction will make the clock audible by means of the telephone, but with varying loudness, according to its relative distances from the bobbins *a* and *c*; but there exists a point on the rod where the induction from *c* is equal to, and entirely neutralizes that from *a*, and absolute silence then ensues. This zero point is nearer to *c* than *a*, on account of the difference in the power of the coils, for if both were equal the zero point would be equidistant between them. The only object in making *a* and *c* of different proportions is to ensure a longer range or scale. The rod is divided into centimetres or any other convenient units. To test the aural power of any person, it is only necessary to place the telephone coil against the bobbin *a*, and slide it slowly towards zero, until the point is reached when the ticking of the clock becomes inaudible; the scale on the rod then indicates exactly the aural power, which can be thus denominated by a number, the value of which may be fixed to any convenient standard.

A second application of Hughes's balance is represented by Fig. 1201. In this a different principle is employed, for whereas in the audiometer one coil is shifted to and fro until perfect equilibrium is attained, in this one a perfect electrical balance is permanently established, and upon its accuracy the delicacy of the instrument depends. It consists of two hollow cylindrical boxes, around each of which are wound two parallel coils. One pair of these is connected by a line, and is placed in circuit with a battery and clock-microphone. The other pair is also connected with a wire, and joined in a telephone circuit. The induction set up in the secondary line, from the current passing through the primary coils, is balanced by the reversal of one of the bottom coils, and adjusted to an absolute silence point. The distance between the two boxes is immaterial. If any metallic substance, a coin for example, be placed in one of the boxes, the balance is destroyed, by the resistance set up in the body of the metallic substance introduced, and the ticking becomes audible, and so delicate can the adjustment be made, that if two coins, similar, but not absolutely identical in weight or

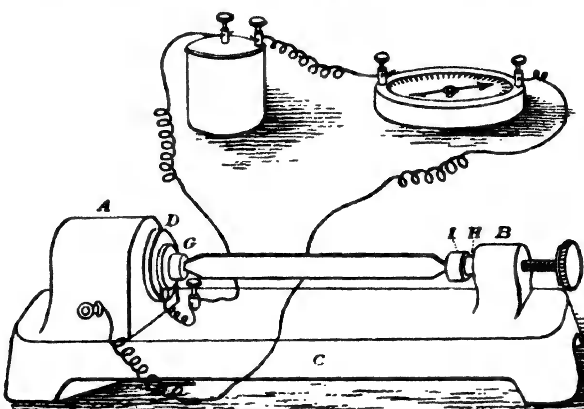
composition, be introduced, the difference can be at once detected by the sound. In this way the existence of impurities in metals, or of inequalities in alloys, too minute to be discovered by analysis, are instantly detected, while perfect similarity is also as instantly proved.

A result of T. A. Edison's experiments with his carbon telephone transmitter, is the construction of an instrument for detecting minute changes of temperature, which greatly surpasses the thermopile in delicacy.

In determining the thickness of carbon buttons best suited to the transmission of articulate sounds, Edison discovered that within certain limits increased thickness gave increased sensitiveness; but after using the instrument a short time it became inarticulate, and finally inoperative. Investigation proved this to be the result of expansion of the hard rubber handle by the heat of the hand. This difficulty was overcome by a different method of attaching the carbon button, suggesting at the same time a new use for its extreme sensitiveness.

The micro-tasimeter, Fig. 1202, consists of a rigid iron frame for holding the carbon button, which is placed between two platinum surfaces, one of which is fixed and the other movable, and a

1202.



device for holding the object to be tested, so that the pressure resulting from the expansion of the object acts upon the carbon button.

Two posts, A B, project from the rigid base-piece C. A vulcanite disc D is secured to the post A by a platinum-headed screw, the head of which rests in the bottom of a shallow circular cavity in the centre of the disc. In this cavity, and in contact with the head of the screw, the carbon button is placed. Upon the outer face of the button there is a disc of platinum foil, which is in electrical communication with the battery. A metallic cup G is placed in contact with the platinum disc.

The post B is about 4 in. from the post A, and contains a screw follower H, that carries a cup I, between which and the cup G is placed a strip of any substance whose expansibility it is desired to exhibit. The post A is in electrical communication with a galvanometer, and the latter is connected with the battery. The strip of the substance to be tested is put under a small initial pressure, which deflects the galvanometer needle a few degrees from the neutral point. When the needle comes to rest, its position is noted. The slightest subsequent expansion or contraction of the strip will be indicated by the movement of the galvanometer needle. A thin strip of hard rubber placed in the instrument exhibits extreme sensitiveness, being expanded by heat from the hand, so as to move the needle of a very ordinary galvanometer through several degrees, which is not affected in the slightest manner by a thermopile facing and near a red-hot iron. The hand, in this experiment, is held a few inches from the rubber strip. A strip of mica is sensibly affected by the heat of the hand, and a strip of gelatine placed in the instrument is instantly expanded by the moisture from a damp piece of paper held 2 or 3 inches away.

The instrument is arranged for these experiments in single circuit, but for more delicate operations it is connected with a Thomson's reflecting galvanometer, and the current is regulated by a Wheatstone's bridge and a rheostat, so that the resistance on both sides of the galvanometer is equal, and the light pencil from the reflector falls on 0° of the scale.

The disturbing effect of electrical induction upon telegraph and telephonic lines, was treated at length by D. E. Hughes, in a paper communicated to the Society of Telegraph Engineers in 1879, and he then detailed a series of experiments, which resulted in the introduction of mechanical arrangements for effectually eliminating, from a group of any number of lines, the effects of induction, assuring the protection of each and all, whether one or more lines are being worked at the same time.

Edison's method, Fig. 1203, simply has reference to the protection of one wire, such as a circuit against the influence of other circuits, without regard to their influence upon one another.

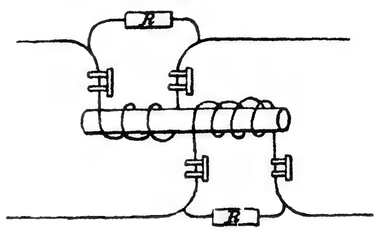
Edison's arrangement consists in placing one or more electro-magnets, Fig. 1203, in the circuit of the telephone, and one or more electro-magnets in the circuit of the adjacent wires, and bringing the opposite cores of the wire magnets at such a distance from the cores of the telephone magnets, that a certain magnetic action will be set up in the latter, by induction in the opposite direction to

the induction currents from the adjacent line or lines. By adjusting the distance between these magnets when the telephone is not in use, until there is not any sound at the diaphragm from the induction currents, then those currents will be neutralized, whether strong or weak, and will not produce any false sounds when the telephone is in use.

C. H. Wilson, of Chicago, was one of the first to point out an arrangement by which two telegraph lines may be compensated for induction. Wilson's device, Fig. 1204, consists of a bar of soft

1203.

1204.



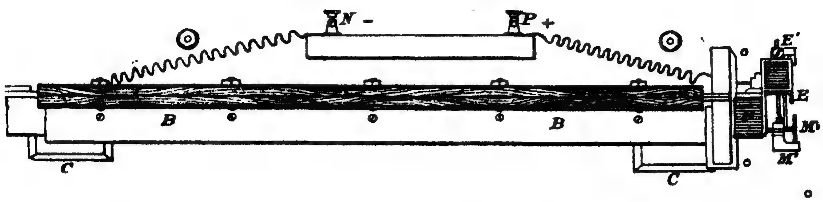
iron carrying two coils of insulated wire, which are respectively placed in the circuits of the two wires. The effect, therefore, of a current traversing one of the coils would be to induce in the other coil a corresponding magneto-electric current, and the coils are so connected to their respective lines, that the currents induced by the coils, are in a reverse direction to those induced by the lateral induction of the line wires. But as a magneto-electric current so produced would in most cases produce a more powerful effect than that due to lateral induction, Wilson short circuits each of the coils, through a resistance box R and R, and these resistances are so balanced against one another, and adjusted for the relative influences of the coils and lines, that mutual compensation is ensured. Electro-magnets are also introduced into the circuits, to act as condensers, for prolonging the duration of the effects produced, so as to make the apparatus equally applicable for long as for short circuits.

Electric Fire-Alarms.—There are many contrivances for automatically announcing the origin of a fire to the inmates of a building or the watchman on duty. A Bain's fire-alarm consists of a column of mercury in a thermometer completing a battery circuit, and sounding an alarm, when the temperature of the locality in which it is placed, rises to a certain degree. This was among the first examples of this species of fire-alarm, and it is one still largely employed in warehouses and in the holds of ships. Many different arrangements have been devised to effect the same purpose, such as inflammable threads and strings passing through apartments, the explosion of bombs, and the dilatation of wires or bars of alloys by increase of temperature, the expansion of air, or some other gas, in a vessel having an elastic wall, and other more or less complex mechanisms. Du Moncel invented an electro-automatic thermometer similar to Bain's, but it was only intended to maintain the temperature of rooms or workshops beneath a certain fixed datum, and not to be a fire tell-tale, although it might have been easily modified for that purpose. It is obvious that such tell-tales with fixed maxima are open to some objection, since, in order to prevent false alarms, it is necessary to know the maximum temperature which the apartment ordinarily acquires, and from the fact that a fire might have broken out, and made considerable headway, in some part of the place, before the fixed maximum temperature was reached on the tell-tale.

All these plans, however, only give the alarm when a certain definite temperature, decided upon beforehand, has been reached. The fire-alarm of Jules Leblanc, of Tourcoing, France, is, therefore, an improvement upon the foregoing methods, inasmuch as it signals all sudden elevations of temperature whatever.

Leblanc's tell-tale will automatically follow or adjust itself to the normal variations of temperature, however high they may be, in the room in which it is placed, and under the influence of a sudden and abnormally rapid rise of temperature will actuate an alarm signal. It is based upon the property which certain materials, such as felt, thick woollens, and the like, possess, of behaving as good conductors of heat, when the heat varies by insensible degrees, like that emitted by the sun or stoves, but as bad conductors when the variation in question is sudden and accidental. It is, in fact, a kind of differential thermometer, regulated automatically. The part sensitive to heat is constructed of zinc, which is one of the metals whose coefficient of expansion is the highest. Fig. 1205 represents an elevation of the apparatus, fixed upon a base of wood little liable to expand and warp under heat; C and C two upright metal supports bolted to the base; between these is a wooden plank on edge, upon which are fastened two expansible plates of sheet zinc, about 60 centimetres long and 0·05 centimetre thick, cut from the same piece so as to expand equally. They are doubled into a gutter shape, to render them more rigid, and are fixed at one end to the support C, while being free to move at the other end through openings in the support. One of these plates, B, is covered with a wrapper of cloth or felt, which retards the effect of sudden changes of temperature on the metal within it; the other plate, on the contrary, is bare, and susceptible to the surrounding changes of temperature. Of exactly the same length and of similar quality, these two plates give sensibly the same linear dilatation for each degree. The two zinc plates are arranged one above the other, with some little space between them; only the upper plate is shown in the plan, Fig. 1205. B′ is a square box soldered to the extremity of the plate B, and E′ is a small bar fixed to the box B′, but isolated from it, and carrying an adjustable contact screw E. By means of this screw the range of the tell-tale is regulated. The head is milled with 120 teeth, and each tooth represents a quarter of a degree of temperature,

so that an interval from a fraction of a degree to several degrees Centigrade, may be at will adjusted, between the contact point of the screw and the spring platinum contact F, attached to the free end of the bare zinc, according to the degree of sensibility required in the apparatus. The bare zinc carries at its extremity a metal piece which has two spring contacts, which are intended to make contact with the screws E and M, when the bare plate expands far enough. M′ is a small insulating bar supported by the base board D, and carrying the second regulating screw M,



which is added to the apparatus as a second tell-tale of the old sort, namely, with a fixed maximum, determined beforehand. It has fifty teeth round its head each representing a degree Centigrade. The screws E and M are connected by wire with the terminal P, to which is led one pole of a battery, and the fixed ends of the zinc plates are also connected by wire to the terminal N, to which is led the other pole of the battery. When the bare plate expands sufficiently far to carry the spring into contact with the screw E the battery circuit will be completed, and a local gong in the circuit actuated. There are small spring ratchets gearing in the teeth of the screws E and M, and holding the latter in their adjusted positions. All the contact points are faced with platinum, to avoid oxidation, and the whole is enclosed in a protecting case to exclude the dust of even the foulest atmospheres. In use the screw E is adjusted so as to leave an interval of one degree between it and the contact spring. So long as the variations of temperature in the room are sluggish, the flannel or felt round the zinc plate B, which carries the screw, will not interfere with the sensitiveness of the plate it covers, and both plates, the covered as well as the bare, will keep pace with each other in their expansion. The relative distance of the two contacts will therefore be preserved with very little alteration, since the screw is carried by one plate and the spring by the other. But if there is a sudden rise of temperature due to any cause, such as the outbreak of a fire, the bare plate will first feel its effects, and expand so rapidly in relation to the plate swathed in flannel, that the spring contact will be carried forward into connection with the screw contact, the electric circuit will be completed, and the alarm will be sounded.

The case of a sudden rise of temperature is that to be most frequently anticipated; but there might be fires which take their rise slowly and gradually; this would prevent the closing of the circuit in the manner described, and defeat the object of the tell-tale. This contingency is provided for by adding to the differential maximum arrangement an auxiliary contact, which takes place at a fixed maximum temperature. The best side for the tell-tale is, usually, near the ceiling of the apartment it is applied to, in some place where heat tends to accumulate under the action of air currents, determined by the disposition of the doors and windows.

Electric Transmission of Power.—As all dynamo-electric machines can be made to yield electricity, through rotation imparted to them by the expenditure of mechanical power, so can this power be reclaimed in part by causing the current generated by one machine to be passed into the coils of a second machine. This second machine will then rotate in an opposite direction, about 50 per cent. of the mechanical power expended upon the pulley of the first machine, being obtainable from the pulley of the second. This is the basis of electrical transmission of power.

The questions of distance to which power may be economically transmitted, and the amount of power transmitted, are limited by considerations of the size of the conducting cable, the size of the generating and receiving machines, and the limit of the magnetic saturation of the iron cores of the electro-magnets in the machines employed. In practice much more will be found to depend upon the limit of magnetic saturation than is generally allowed.

As a matter of fact, however, where as much power as can be got through a cable is to be transmitted, the thickness of the cable required to convey such power is of no particular moment, and Professors Houston and Thomson state that it is possible, should it be deemed desirable, to convey the total power of Niagara, a distance of 500 miles or more, by a copper cable not exceeding ½ in. in thickness. This is an extreme case, and engineers in practical working would not require such restrictions as to size. The following considerations will elucidate this matter. Suppose two machines connected by a cable of, say, 1 mile in length. One of these machines, for example, A, is producing current by the expenditure of power; the other machine, B, used as an electrical motor, is producing power by the current transmitted to it from A by the cable C. The other terminals, and y, are either put to earth or connected by a separate conductor.

Let it be supposed that the electro-motive force of the current which flows is unity, since, by the revolution of B, a counter electro-motive force is produced to that of A, the electro-motive force of the current that flows is manifestly the difference of the two. Let the resistance of A and B together be equal to unity, and that of the mile of cable and connections between them the 0·01 of this unit.

Then the current which flows will be $C = \frac{E}{R} = \frac{1}{1\cdot01}$. If, now, an additional machine A′, motor

B′, and an additional mile of cable be introduced into the above circuit, the electro-motive force will be doubled, and the resistances will be doubled, the current strength remaining the same, as

$$C = \frac{E}{R} = \frac{1+1}{1\cdot 0+1\cdot 01} = \frac{2}{2\cdot 02}.$$

Here it will be seen that the introduction of the two additional machines A′ B′, has permitted the doubling of the strength of the current which flows, and yet allows the expenditure of double the power at A A′, and a double recovery at B B′, or, in other words, a double transmission of power without increase of current.

Increasing the number of machines at A, say to one thousand, and of those at B in like proportion, and the distance between them, or in the case supposed one thousand miles, the diameter of the conducting cable remaining the same, then, although the same current will flow, yet there will be a thousand times the expenditure of power at one end of the cable, and a thousandfold recovery at the other end, without increase of current. And the same will be true for any other proportion.

Since the electro-motive force is increased in proportion to the increase of power transmitted, the insulation of the cable and machines would require to be proportionally increased.

As an example, it may be mentioned that a dynamo-electric machine used for A may have a resistance of, say, 40 ohms, and produce an electro-motive force of, say, 400 volts. Such a machine would require from 3 to 5 horse-power when used in connection with a suitable motor B, for recovery of the power transmitted.

If the resistance of the motor B be, say, 60 ohms, and the cable transmitting the currents a distance of 1 mile be 1 ohm, then the currents $C = \frac{400}{60+40+1} = \frac{400}{101}$. If 1000 machines and 1000 motors and 1000 miles of cable, each of the same relative resistances, be used, the current $C = \frac{1000 \times 400}{1000 \times 101}$, which has manifestly the same value as before. If the supposition of the power used to drive one machine be correct, then from 3000 to 5000 horse-power would be expended in driving the machines, and about 50 per cent. of this amount recovered. Then there would be from 1500 to 2000 horse-power conveyed a distance of 1000 miles. What diameter of copper cable will be required for such transmission? Since this cable is supposed to have the resistance of 1 ohm to the mile, calculation would place the requisite thickness at about ¼ inch. If, however, the distance be only 500 miles, then the resistance a mile may be doubled, or the section of the cable be decreased one-half, or its diameter will be less than one-fifth of an inch.

For the consumption of 1,000,000 horse-power a cable of about 3 in. in diameter would suffice under the same conditions. However, by producing a much higher electro-motive force, the section of the cable would be proportionally reduced until the theoretical estimate might be fulfilled. The enormous electro-motive force required in the foregoing calculation would, however, necessitate such perfect insulation of the cable, that the practical limits might soon be reached. The amount of power required to be conveyed in any one direction would, of course, be dependent upon the uses that could be found for it, and it is hardly conceivable that any one locality could advantageously use the enormous supposed power referred to.

Stripped of its theoretical considerations, the fact still remains, that with a cable of very limited size, an enormous quantity of power may be transferred to considerable distances.

In a subsequent series of experiments, details of which are unpublished, the Professors Thomson and Houston have succeeded in transmitting considerable power through a wire only 0·004 in. in diameter. W. Thomson has made statements that are in general accordance with these views. C. W. Siemens has remarked that the electrical transmission of power, although new and untried, is one of considerable interest, and an amount of from 40 to 50 per cent. is recovered at the end of the line.

A 100 horse-power engine, economically constructed, would produce 1 horse-power with less than 3 lb. of coal, whereas a small motor of 2 or 3 horse-power would consume probably 6 to 8 lb. of coal an hour. Bearing that difference in mind, the magneto-electric machine would be an economical one.

P. Higgs has stated that the limit set by distance to the transmissions of power, by means generally adopted, has been comparatively narrow. Hydraulic power has been the most adaptable, with, however, several important disadvantages. Although electricity as a means of transmission is also limited by the distance to be traversed, the limit is in this case much more extensible, and under favourable instances practically disappears. The limit is dependent upon the quantity or intensity of electricity that can be conveyed by the conductor, since mechanical efficiency depends upon the magnetic energy. For the transmission of power, say from a steam or water motor initially, the following system is adopted. First, a strap or belt from the motor is carried to the pulley of the driving dynamo-electric machine, which generates the current. By leading wires of the required length, the electrical current generated in the first machine is conveyed to the terminals of a second and precisely similar machine. Thus the first machine generates the current which is utilized for imparting motion to the second machine.

The probable efficiency of such a system has been treated in its mathematical relations by M. Mascart. It is well known that all magneto-electric machines, when set in motion by a current, induce in themselves, as electrical systems, currents opposing the motive current. For example, when a current from some other source is directed into the coils of a dynamo-machine, the coil commences to revolve. Immediately it commences to revolve, it also begins to act as a generator, and sets up a current which is opposite in direction to the motive current, and subtractive from the strength of the latter. The current strength from the source is therefore at a maximum when the second machine, or that driven by the current, is at rest. From consideration it is easily obtained that the greatest work to be yielded by the second machine, is when the strength of current given by the first machine, or source, has been reduced to one-half by the induced current

from the second machine. With these machines it has been generally found that the current strength is proportional to the velocity, or number of revolutions of the cylinder; so that, supposing two equal machines arranged for the transmission of power, the amount of work reclaimable from the second machine will be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine, corresponding to the maximum of work reclaimed, will be half the number made by the first.

P. Higgs has given the following results of experiments, Table VIII., with dynamo-machines for the transmission of power by the electro-current;—

TABLE VIII.

Machine A, at 1100 Revolutions, driving C.		Machine A, at 1100 Revolutions, driving B.		Machine A, at 1400 Revolutions, driving B.	
Revolutions of C.	Per Cent. of Work Reclaimed.	Revolutions of B.	Per Cent. of Work Reclaimed.	Revolutions of B.	Per Cent. of Work Reclaimed.
1008	27	884	34	1199	39
730	36	808	43	1031	44
584	38	767	44	863	48
501	39	625	45	691	49
420	37	481	39	500	37
359	35	385	32	..	..

The departures from the theoretical values are somewhat marked, but are within the limits of error that occur with this class of measurements, made with no great attempt at accuracy. In these experiments, in order to ascertain the effects of resistance in the circuit connecting the driving and driven engines, two machines were connected by leading wires, having resistance of ½ unit, 1 unit, and 1½ unit, respectively. The machines gave without inserted resistance an efficiency of 44 per cent.; with ½ unit resistance added to the circuit, the efficiency was reduced to 38 per cent., giving a loss of 6 per cent.; with 1 unit of added resistance the efficiency fell to 32 per cent., giving a loss of 12 per cent.; and with 1½ unit added resistance the efficiency was 26 per cent., giving a loss of 18 per cent. The experiments clearly proved that the loss of efficiency is proportional to the added resistance.

With a machine having 0·05 unit resistance, a current of 5 webers through 1 ohm has been obtained, with an expenditure of 2 horse-power. This gave a current, of which the mechanical value, when the machine was connected to a precisely similar machine, was 56,000 foot-pounds, with the second machine at rest; and a resultant current of 29,000 foot-pounds with the second machine in motion, the horse-power expended being maintained constant. The work reclaimed, measured on the dynamometer, was 48 per cent., closely agreeing with the efficiency of one-half. As to the effect of circuit resistance on the transmission of power in the instances quoted, the addition of 1½ unit resistance reduced the efficiency to 26 per cent., with the particular machines employed; but if convolutions of wire were added to the cylinder of the machine, the efficiency would again attain its maximum. It should be noted that the theoretical efficiency of 50 per cent. is referred to the use of two equal and similar machines, one used as the driving, the other as the driven machine. It is quite probable that a larger percentage of work reclaimed might be attained by some other arrangement of machines.

By driving one machine by two others coupled in series, the results of three readings gave speed of small machines, 1060 revolutions; speed of medium machine, 1820 revolutions. The medium machine driven by one small machine, gave the following results, taken from three readings; speed of small machine, 1060 revolutions; speed of medium machine, 780 revolutions. It would thus be seen that the speed of the medium machine had been rather more than doubled by driving it from two machines coupled in series. The best conditions for work admitted of direct proof. Two equal machines being employed, and a galvanometer put in circuit between them, the deflections showed that when the second machine was at rest, the current was of twice the intensity that occurred when the second machine was giving out its best work.

This amount of reclaimed power is indubitably superior to that obtained with compressed air, and approaches the practical efficiency of hydraulic transmission. Electric transmission has, however, the unparalleled advantage of being superior to the obstacle presented by distances, whilst it is at the same time easily portable, and can be changed in direction, as well as in intensity, at will. No force appears in the connecting portions or conductor, such as appears during mechanical transmission with shafting, or in pipes with compressed air or water. The conductor appears inert, and can be shifted, bent, or in any way moved whilst transmitting many horse-power. Its continuity must not, of course, be interrupted.

The source of power and the point of reclamation may be relatively situated most awkwardly, but the electric conductor can be brought round the sharpest corner, or carried through the most private room without inconvenience. There is nothing to burst or give way. The same circuit as may be tapped to provide the means of working power machinery can be as conveniently utilized to work a sewing machine.

See BLASTING, p. 133. CHIMNEY SHAFTS, p. 355. DYNAMO-ELECTRIC MACHINES, p. 475.

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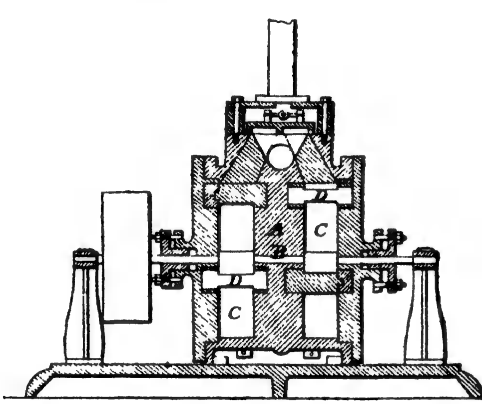
ENGINES, VARIETIES OF.

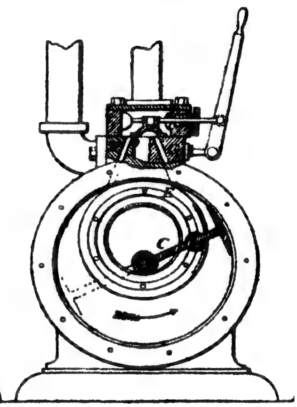
Amongst the many varieties of the steam engine, the rotary engine has not realized that efficiency which its comparative simplicity would appear to warrant. There are many forms of the rotary engine, but those in Figs. 1206 to 1209 are of especial interest, as their capabilities have been carefully tested.

The Myers' engine, Figs. 1206 and 1207, has an inner case E, set eccentric to the outer cylinder, and revolving in a groove, so that the top portion forms an abutment. The piston C is secured to the shaft, and has a toggle-joint connection with the case at D. The piston also has a long fluke or lug

1206.



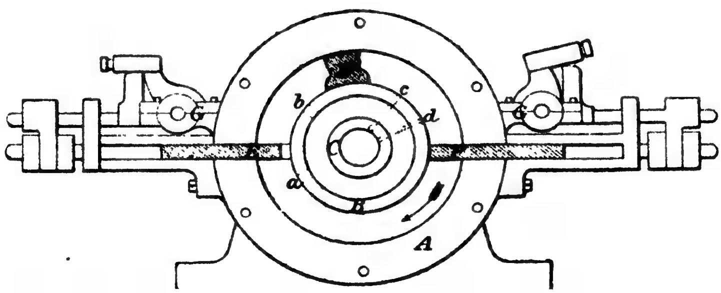
1207.



at the end. The cylinder is divided into two compartments, each of which contains one of these cases and pistons, the two pistons being set at right angles to each other. Steam is admitted through a valve and ports, F and G.

The Gallahue engine, Fig. 1208, consists of a casting A, which includes the main cylinder, in which works the piston D, firmly attached to the inner revolving cylinder B, and there are two sliding abutments E and F, actuated by cams. Steam enters and is exhausted at the ends by steam ports *a b* and exhaust ports *c d*.

1208.



In the Massey engine, Fig. 1209, the outer case E is oval, and the inner cylinder G is secured to the shaft F. The pistons H H are moved in and out by the action of fixed cams I. L is the abutment. At D is a valve, controlled by the lever C, which admits steam through the passage A; the exhaust is arranged on the opposite side at B.

The Lidgerwood engine consists of an outer cylinder, oval-shaped, and an inner cylinder or case, circular in section, secured to the shaft, and forming two abutments at its points of contact on each side with the outer cylinder. Six pistons are arranged in the inner case, actuated by fixed

cams, the form of the outer cylinder being such that the pistons do not slide when they are under pressure.

The rotary steam engines above described, were carefully tested in 1874 at New York by J. T. Hawkins, and the results of these tests are recorded in Tables I. and II.

1209.

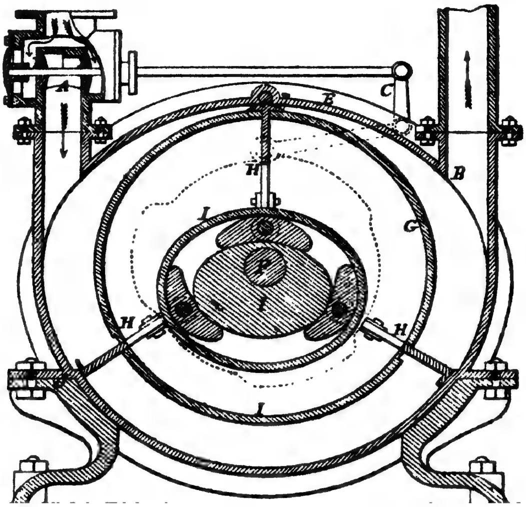


TABLE I.—TRIALS OF ROTARY ENGINES. OBSERVATIONS.

Quantity.	Lidgerwood.	Gallahue.	Massey. First Trial.	Myers.	Massey. Second Trial.
Length of run	5 hours.	5 hours.	50 min.	5 hours.	5 hours.
Pressure of steam by gauge	77·43	74·68	82·4	65·41	66·08
Pressure of exhaust by gauge	1·95	0·7	0	0·106	0·38
Revolutions a minute	117·19	133·46	260·9	186·83	193·37
Unbalanced weight on brake, in pounds	16	6	6	6	16
Reading of brake scale, in pounds ..	57	20·65	27·5	60	34·63
Lever arm of brake, in inches	65·75	60·25	60·25	60·125	64·625
	deg.	deg.	deg.	deg.	deg.
Temperature of water entering tank ..	50·39	52·74	51·7	49	47·5
Temperature of discharge water	106	114·49	151·3	136·95	126·52
Temperature of the air	55	55	55	55	55

An examination of the Gallahue engine made after the test, showed that the sliding abutments were so adjusted as to allow steam to blow through continuously. In the first trial of the Massey engine the main bearings were so abraded that it was necessary to stop. This was obviously due to insufficient bearing surface, and larger bearings have been fitted; the engine afterwards made a run of five hours successfully.

The Outridge box engine consists of a cast-iron casing forming a cylinder traversed at the middle of its length by the crank shaft. The piston is formed of two rings connected by means of distance pieces, while a plate is secured at each end, and between these plates the sectors, which act as connecting rods, move freely. Figs. 1210 and 1211 are a vertical longitudinal section and a transverse section respectively of a two-cylinder engine on this principle.

The sectors roll on the inner faces of the piston, and are supported by bridle rods of wrought iron, the wearing parts being case-hardened, and the pins on which they move of steel. In the ends of the sectors are fitted the crank-pin brasses, so arranged that they may be screwed up until they are completely worn through; the motions of the arcs of the sectors being a rolling motion, there is little friction.

The valves are of cylindrical form, having passages for the inlet and outlet of the steam, one valve being placed at each end of the cylinder. They are held between centres of hardened steel, and are actuated by an eccentric attached to a rod connected to both by means of short levers; the motion of the eccentric causes the valve to vibrate. The engine is under the control of the reversing lever, and may be stopped, started, reversed, or linked up with ease, the valves always being in equilibrium.

The clearance spaces are small, the amount being only one-fourth part of the cubic contents of the cylinders, as compared to one-twelfth part, which is the general practice in small engines of

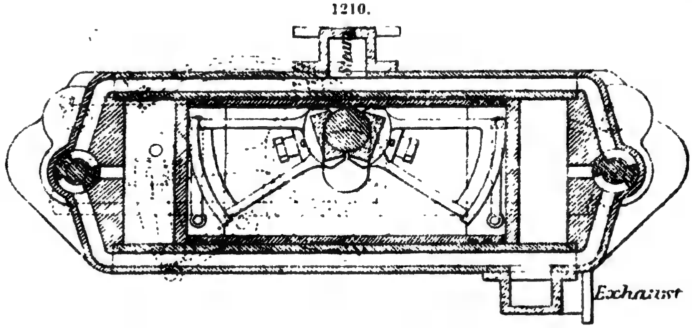
ordinary type. This object is gained by the use of very short steam ports, usually ⅜ inch in length.

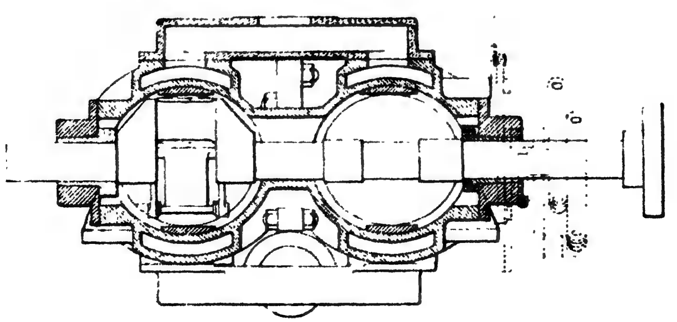
TABLE II.—TRIALS OF ROTARY ENGINES. CALCULATED RESULTS.

Quantity.	Lidgerwood.	Gallahue.	Massey. First Trial.	Myers.	Massey. Second Trial.
Absolute pressure of steam in pounds on the sq. in.	92·115	89·365	97·085	80·095	80·765
Temperature of steam .. deg.	321·7	319·6	325·5	312	312·5
Latent heat of evaporation ..	888	889·5	885·3	895	894·6
Weight in pounds of a cub. ft. of water at the different temperatures	61·92	61·801	61·178	61·449	61·613
Pounds of water discharged from tank an hour	12995·77	12970·79	12840·04	12896·92	12931·34
Units of heat lost an hour by radiation and evaporation ..	13616·21	13590·04	26906·08	20268·95	20323·05
Units of heat discharged from tank an hour	722694·77	800946·28	1278867·98	1134284·11	1021834·49
Pounds of steam used an hour ..	667·13	744·13	1232·45	1042·43	964·44
Effective horse-power	5·013	1·869	5·362	9·624	3·694
Assumed indicated horse-power	7·168	2·673	7·668	13·763	5·282
Pounds of steam an effective horse-power an hour	133·09	398·12	229·83	108·32	261·08
Pounds of steam an assumed indicated horse-power an hour	93·07	278·41	160·72	75·74	182·59
Pounds of coal assumed indicated horse-power an hour ..	10·34	30 93	17·86	8·42	20·29
Pounds of coal effective horse-power an hour	14·79	44·24	25·54	12·04	29·01

A lubricator is fitted on the steam pipe, and the oil is carried past the valves into the interior of the cylinder in the usual manner. An oil cup is also fitted to the hand-hole door, by means of which oil is introduced between the inner faces of the piston plates; thus the crank pin is prac-

1210.



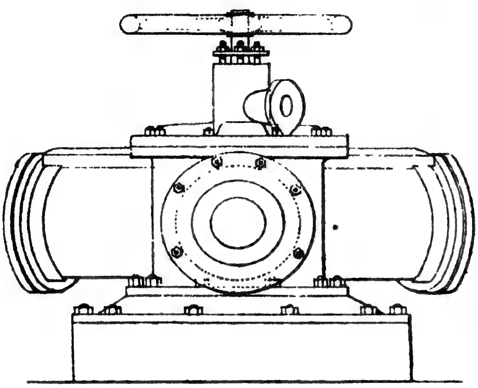


1211.

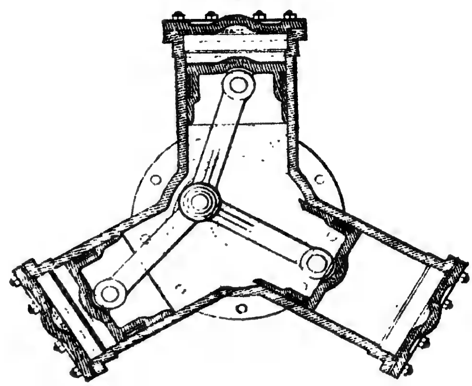
tically submerged at each revolution, the splashing caused by the passage of the crank through the oil, thoroughly lubricates all the working parts enclosed within the diameter of the cylinder, and oil-ways are cut in the bearing brasses, through which the oil constantly trickles and thereby reduces the chances of hot bearings.

In Brotherhood's engine, Figs. 1212 to 1214, three cylinders are arranged at angles of 120° with each other, around a central chamber with which they communicate, the whole being cast in one piece. Each cylinder has its own piston and connecting rod, the three rods taking on to one common crank. The crank pin, after passing through the connecting-rod eyes, is prolonged, and fits into a hole in a rotary slide valve which it actuates. The valve has a steam and exhaust port, which

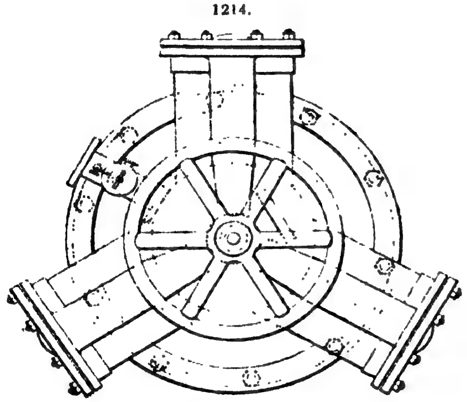
1212.



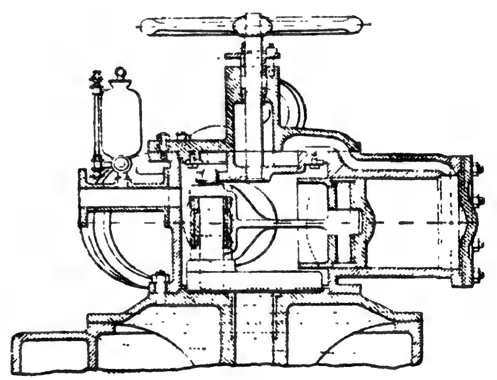
1213.



1214.



1215.



are alternately placed in communication with the passage belonging to each cylinder. In working, steam is admitted to the central chamber, and exerts an equal pressure on the inner sides of the three pistons. Thus far the machine would be in equilibrium. But steam now passes the slide valve to the outer side of one piston, thus throwing that side into equilibrium; but the three pistons collectively out of equilibrium. In other words, it renders the pressure on the inner sides of the other two pistons effective. A rotary motion of the crank and slide valve ensues, and the other pistons are alternately operated upon in similar manner; the constant effective area for pressure being that of a piston and a half. If steam is not admitted during the whole of the inward stroke of a piston, it follows that the piston is not entirely thrown into equilibrium, and the crank has to assist it in the return stroke. The effect is equivalent to working steam expansively in an ordinary engine.

A piston, when working in one direction, pulls the crank, and when moving in the other, is pulled by the crank. Hence, the strain on its connecting rod is always a tensile one. No knock can therefore take place in the connecting-rod eyes on the alteration in the direction of the piston's movement; so the fit may be everywhere quite loose, and instead of constantly adjusting brasses, it is only necessary to renew a few bushes when excessive wear has taken place. Similarly the slide valve is free to slide on the crank pin, and adjust itself to its face as wear takes place, and the back of the crank disc always maintains a steam-tight joint in the same manner. The lubrication at first proved a source of difficulty, but is now amply secured by the addition of an impermeator to the steam pipe, the oil being carried by the steam as a medium to all the working parts.

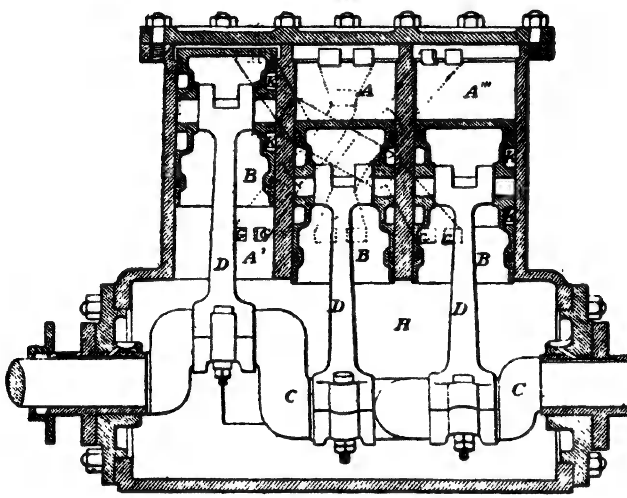
In the course of a series of experiments undertaken with the view of determining the point, it was found that few metals would stand heavy work in high-pressure steam under such conditions. Ultimately, hard phosphor-bronze bushes for the connecting-rod eyes, working on a hardened steel crank pin were adopted, and these are found to last a long time without any oil, the steam affording sufficient lubrication for these two metals. The machines being well balanced, high speeds

are permissible. An average speed of even 300 ft. a minute for the piston gives a very high indicated horse-power in proportion to the size and cost.

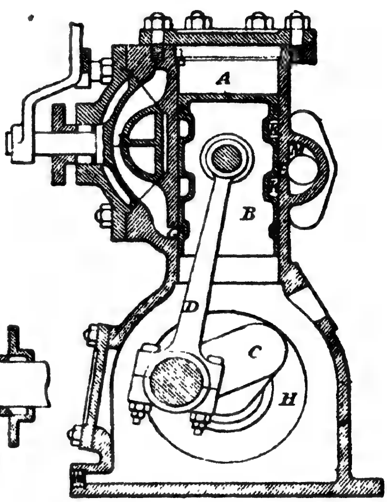
It should be observed that the circular valve with which this engine is fitted, whilst possessing the advantage of great simplicity in its construction and working, differs from other rotary valves only in its form, but not in its principle, and shares equally with them the defects of uneven wear; this renders it difficult to retain it unimpaired in working order; and the circular valve is therefore mostly found in those types of high-speed engines where economy in the consumption of steam is deemed of secondary importance. Such is the case with Brotherhood's engines, which, although particularly adapted for the direct driving of circular saws, centrifugal pumps, electrical and other machines requiring high speeds, cannot be recommended for general use on account of their heavy consumption of steam, except where this is of little moment, or where the attainment of speed is a paramount consideration.

Figs. 1216, 1217, are of Willan's three-cylinder engine, as constructed by Tangye; each piston forms a valve to one of the other cylinders. The cylinders A'A A''' are single acting, and are placed side by side, the pistons, which are arranged side by side, driving, by means of the connecting

1216.



1217.



rods D, three cranks placed at an angle of 120° with each other. The steam inlet is at M, this steam chamber communicating by ports E with each cylinder. Through these ports the steam passes into a groove K, and when a piston, as for instance that moving in the cylinder A''', has made about five-eighths of its downward stroke, the steam passes from this groove K into a port G formed in the side of the cylinder, and thence is led through a passage to the top of one of the other cylinders. On its way the steam traverses the reversing valve L, and it is the position of this valve which determines to the top of which cylinder the steam thus admitted by the action of the piston B is led, this also determining the direction of motion of the engine and completely controlling it. The steam admitted to a cylinder by the downward movement of one of the pistons as above described, is cut off by the subsequent upward movement, while a continuation of this upward movement causes the port G to be uncovered by the piston, the steam being thus allowed to exhaust into the casing H surrounding the crank shaft. The pressure exerted by the steam being always in one direction, the engine can be run at considerable speed without noise or inconvenience, while the distribution of steam effected is very good.

The six-cylinder engine of D. K. West, Figs. 1218 and 1219, consists of a base plate carrying a casting containing six cylinders, arranged in a circle with their axes parallel to the main shaft *a*, which traverses the centre of the casting. Each cylinder is fitted with a hollow piston, each piston having a conical end P which bears against a disc D, Fig. 1219.

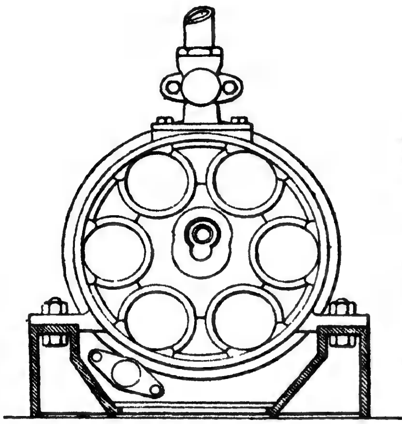
The disc is mounted on a short shaft C, having at one end a spherical bearing E, while the other enters a brass bush fitted to the crank arm B, this crank being keyed on the main shaft *a*. The shaft makes one revolution for every complete double stroke of each piston, and as each acts during a semi-revolution, the six coming into operation in succession at intervals of 60°, there are three pistons constantly acting on the disc, and the strain thrown upon the crank and shaft is thus practically uniform. There is thus no dead point, and a flywheel is rendered unnecessary.

The arrangement of the slide valves and cylinder ports is shown in Fig. 1220. There is keyed on the shaft *a* an eccentric *b* which works within a loose ring *c*, and thus gives motion to the outer ring *f* which constitutes the valve. The section of *f* is such as to give it some elasticity, and enable it to adapt itself to the two surfaces between which it works. The inner ring is made in two parts, *c* and *d*, the requisite elasticity in this case being obtained by the introduction of a packing ring of U shape.

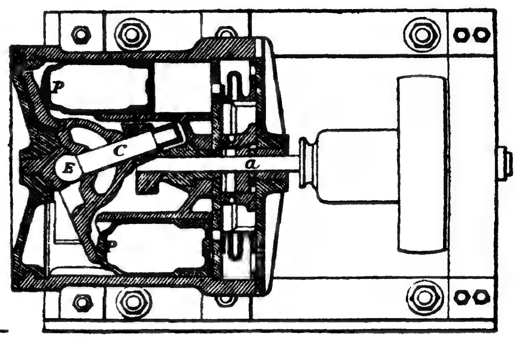
The steam enters the space between the valve rings *c* and *f*, through the three oval ports, and it is thence, by the movement of the valve, admitted to and released from the six cylinders successively. The ports to the cylinders are short, as they only have to extend through the plate which

divides the cylinders from the valve chest. The engines can thus be made with exceedingly small clearance spaces. The exhaust steam escapes past the outer edge of the ring *f*, and thus enters the outer part of the valve chamber, from which it is let off by a pipe from the bottom as in Fig. 1218. The motion given to the valve greatly tends to promote equal wear, the valve being quite free to turn round under the action of the eccentric, so that all parts of the rings are brought successively into contact with the different portions of the faces on which they work.

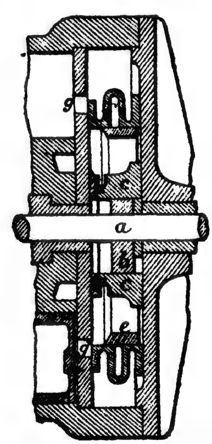
1218.



1219.



The mode of action of the engine will be readily understood. Let it be imagined for a moment that the crank shaft is vertical, and let it be turned by hand. Then as the crank is turned, the part of the disc opposite to it is always in the highest position, but as the disc does not revolve, the part which is the highest is constantly changed, and every point is raised and depressed during each revolution of the crank.



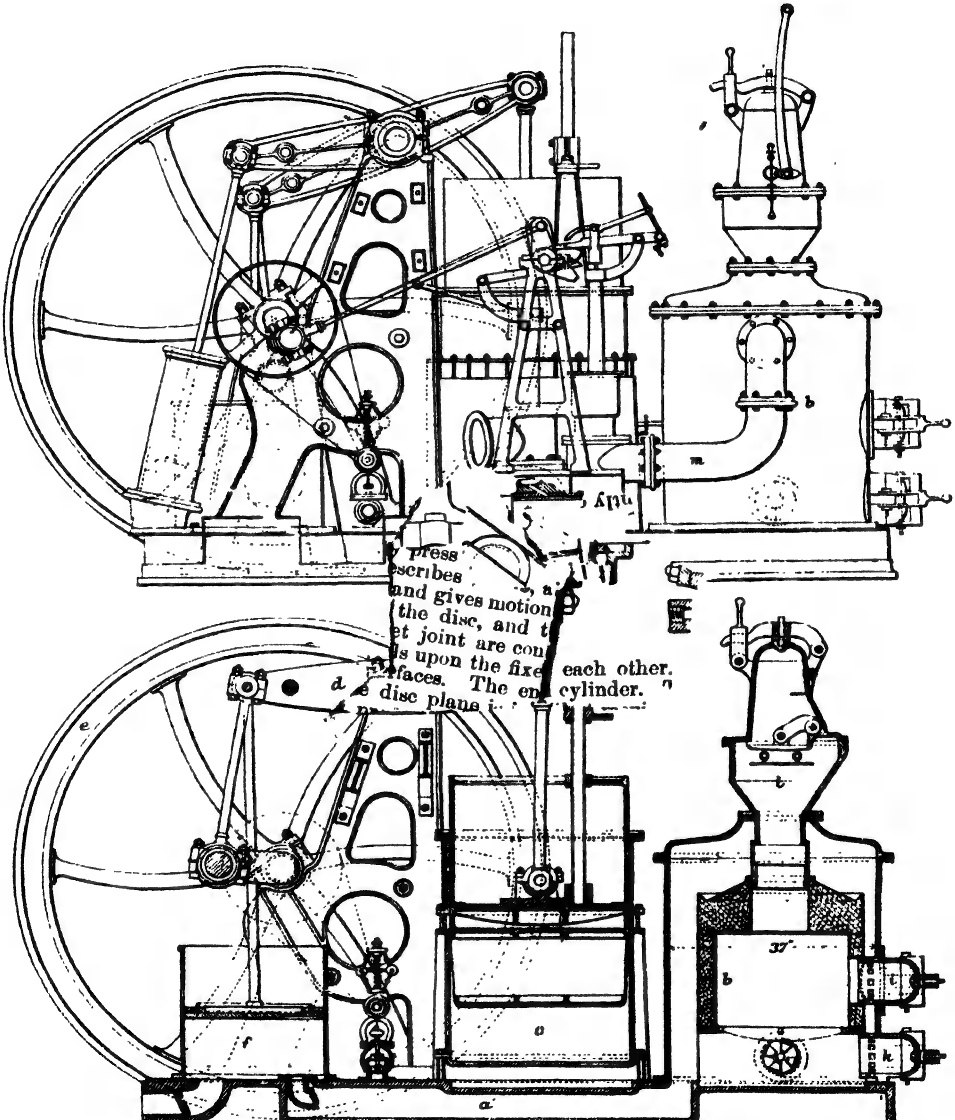
In working, as the pistons successively press upon the part of the disc before them, the axis of the crank pin describes a cone, and the end in a crank revolves in a circle about the shaft and gives motion to the latter by driving the crank. The outer surface of the disc, and the metal at the back of the engine about the ball-and-socket joint are coned to a bevel, so that as the engine works the disc cone rolls upon the fixed cone, and the whole pressure is borne by the rolling surfaces. The ends of the piston are also coned to the angle at which the disc plane is inclined, and they have a similar rolling contact, always presenting a radius of an obtuse cone to the plane, and thus giving a broad surface of contact to bear the pressure. The back cover of the engine is secured to the main casting by a simple form of bayonet joint, and it can thus be readily removed when any of the parts require examination. A small pipe is fitted to the main casting to lead off any steam which may leak past the pistons; but unless such leakage exists, no steam gets to the crank, or crank-pin bearing.

Gas engines and heat engines of good design are of considerable service in situations where questions of cost, convenience, and the like, prohibit the use of steam. Gas engines can in addition be made to develop considerable power, and they have the advantage that they are ready at a moment's notice without the delay caused by lighting fires, or getting up steam, or the expense of keeping up pressure during intervals in working, they require but a small amount of attendance, and are free from the dangers of explosion. In the smaller manufacturing industries they are of especial service, and frequently may be employed with advantage to supplement the work of a factory engine with economical results.

Heat engines are suitable for situations where gas cannot be conveniently obtained, and have been largely employed for pumping water, driving magneto-electric machines, and similar work in isolated situations, such as detached country mansions, forts, lighthouses, and the like.

Figs. 1221 and 1222 are an elevation and section respectively of a 10 horse-power caloric engine, made by A. and F. Brown, of New York. It is single-acting and has a bed plate *a*, heater *b*, working cylinder *c*, beam *d*, flywheel *e*, air-compressing pump *f*, and valve gear *h*. The heater *b* is composed of a cast-iron cylinder, and is fitted with a firebrick furnace. Two cast-iron pipes, *k*, fitted with air-tight doors, one for access to the furnace, and the other to the ash pit, are provided. Slots are formed in these pipes, to afford communication between the furnace, ash pit, and the annular space referred to. A feeding hopper *l* is also fitted to the crown of the furnace, and is provided with two air-tight doors, one opening outwards and the other inwards. The inner door is provided with a deflecting plate, to protect it from the intense heat of the furnace. The space between these doors is sufficient to contain fuel for one charge. The fuel, anthracite coal, or coke, is introduced to the furnace by closing the outer door and depressing the inner one, by means of a lever. The air pump *f*, which is single-acting, has a piston stroke of 20 in. It compresses and delivers air to the heater through a channel *a'* in the bed plate, where it supports combustion, and

is expanded to a pressure of about 26 lb. a sq. in., whence it is conveyed by a pipe *m* connecting the crown of the furnace with the working cylinder, its admission being controlled by a double-beat inlet valve, actuated by a rock shaft, eccentric, and tappet valve gear *h*. The compressed air delivered by the air pump into the annular space of the heater, enters at the bottom in the bed plate, and passes into the furnace through the slots in the cast-iron pipes *i k*. The expanded air, having done its duty in the cylinder, is permitted to escape into the open air by means of an outlet valve actuated similarly to the inlet valve. The down stroke of the engine is performed by the



1222.

momentum of the flywheel and the descending parts. The working cylinder is fitted with a trunk piston, which is kept tight by leather packing secured to the mouth of the cylinder. The engine is fitted with a sensitive governor, makes sixty revolutions a minute, and works smoothly and with great regularity. The small air pump, Fig. 1221, which is also single-acting, 20 in. stroke, is used for compressing air to 50 lb. a sq. in. for sounding the Siren fog signal when the engine is employed for work at a lighthouse. These engines are stated to work upon the moderate consumption of 30 lb. of coke an hour, being equal to 3 lb. to each effective horse-power an hour.

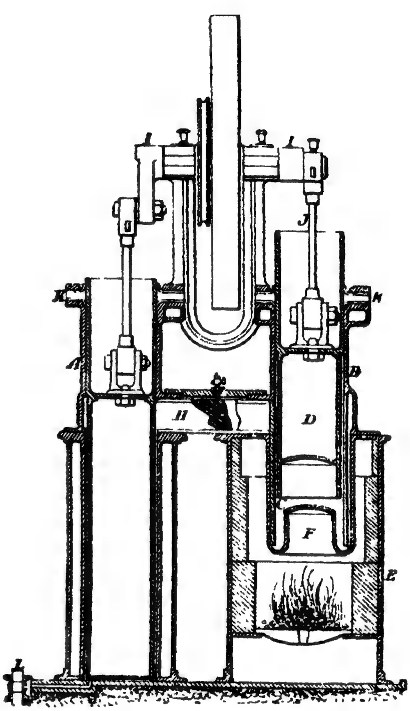
A small hot-air engine is generally required, however, to fulfil two sets of conditions; to be moderately economical in its working, and to be simple, straightforward, and easily managed by

untrained hands. The hot-air engine, invented by A. K. Rider of New York, and made in England by Haywood, Tyler, and Co., London, is an efficient and simple motor; it possesses few working parts and those of a very simple kind, and no valves. The use of a regenerator enables it to attain some degree of economy, for it is hardly possible for an air engine to be economical in practice without the regenerator.

Fig. 1223 is a section of Rider's engine which consists of a compression cylinder A, and a power cylinder B, with pistons D, and connections, and a regenerator H.

The lower portion of A is kept cold by a current of water circulating through the cooler, which surrounds the lower portion of this cylinder; the lower portion B is kept hot by the action of the fire below the heater F. The heating, and also the cooling of the air, is quickly effected by its alternate presentation to the surfaces of the heater and cooler, in a thin annular sheet. The piston of A extends downwards to the base of the engine, and is a trifle smaller than the cooler, thus leaving a thin space on all sides for the air to pass downward and become cool on its way to the bottom; through this space it also flows on its way back to the heater. The power piston D likewise extends downwards into the heater F, shaped to rise in the centre, and present to the action of the fire a narrow annulus all around the bottom. C is a thin iron cylinder, about one-fourth of an inch less in diameter than the interior of the heater. It is fitted to the interior of the power cylinder B, and extends nearly to the bottom. Its office is to cause the air which flows from the compression cylinder to be presented in a thin sheet all around the interior surface of the heater, and particularly at the lower and hotter portion. By this means the air is thoroughly and rapidly heated.

1223.



The same air is used continuously, being merely shifted from one cylinder to another.

The regenerator H is composed of a number of thin plates slightly thickened at their edges, which, while affording a free passage to the air, subdivides it into sheets. It is so placed between the cylinders as to be replaced by the air in its passage each way. Thus the heat is alternately abstracted from, and returned to the air, in its passage backwards and forwards through these plates, imparting economy of power and steadiness to the engine.

The pistons are attached to cranks I I, which stand at an angle of 95° with each other, the crank of the power piston being in advance, by connecting rods J J.

K K are leather packings. The lower one has its lap downwards to resist the escape of air below the piston, the upper one its lap upwards to prevent the lubricating material from entering too freely into the cylinders. Between them is the relief ring, to relieve the friction of the packings.

L is a check valve to supply any leakage of air which may occur. It is generally placed at the back of the engine, at the lower part of the compression cylinder, but is here shown on the other side.

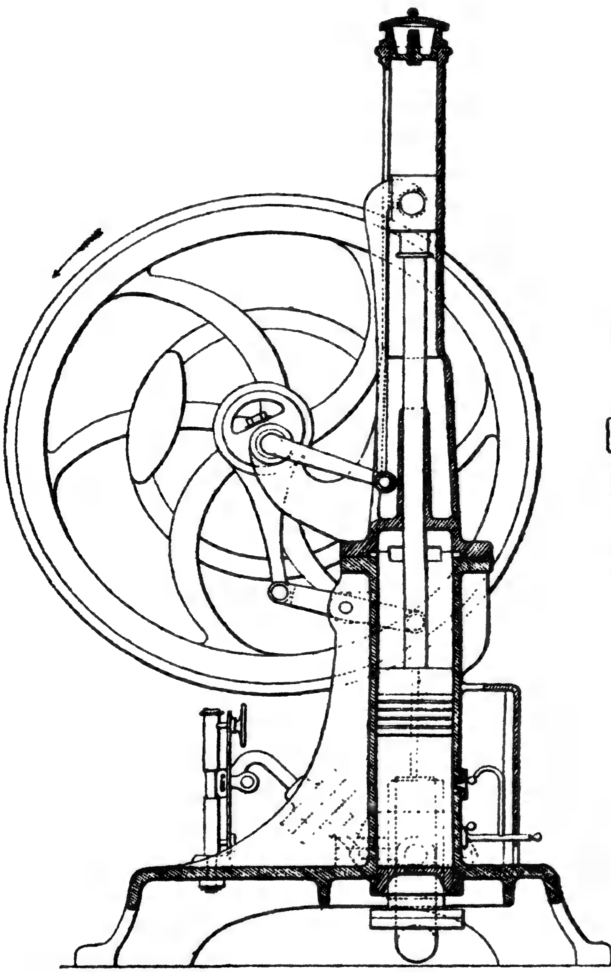
In working Rider's engine, the piston of A compresses the cold air in the lower part of A into one-third its normal volume, when, by the upward motion of the piston D, and the completion of the down stroke of A, the air is transformed from A, through the regenerator H, and into the heater F, without appreciable change of volume. The result is a greater increase of pressure, corresponding to the increase of temperature, and this impels the power piston up to the end of its stroke. The pressure still remaining in the power cylinder and reacting on the compression piston, forces the latter upwards till it reaches nearly to the top of its stroke, when by the cooling of the charge of air the pressure falls to its minimum, the power piston descends, and the compression again begins. In the meantime the heated air in passing through the regenerator, has left the greater portion of its heat in the regenerator plates, to be imparted and utilized on the return of the air towards the heater. This process recurs at each revolution.

The Bischoff gas engine, Figs. 1224 to 1226, has a breastplate, with which the vertical cylinder is cast, as well as the valve chamber, and the cylinder cover and stuffing box prolonged above to form a guide for the piston-rod head, and having the earing bracket for the shaft cast along with it. The space above the piston communicates freely with the air by the rectangular opening, Fig. 1224. The bottom of the cylinder has a single port communicating with the chamber of a plain piston valve, which when raised opens communication with the exhaust, and when down, as in Fig. 1225, connects the cylinder with the gas and air inlet openings. This valve is worked by an ordinary eccentric through the intervention of a rocking lever. The eccentric is placed about 135° in advance of the crank. At a third of the stroke up the cylinder there is a little opening on one side of the latter, opposite which, outside, is the nozzle of a small gas pipe; and directly below this nozzle is an ordinary burner, connected with the same pipe, the gas at which is kept always lighted, Fig. 1224. The two gas burners are protected from draughts by enclosure in a box casing. The upper burner is the real ignition jet, the function of the lower one, which is burning

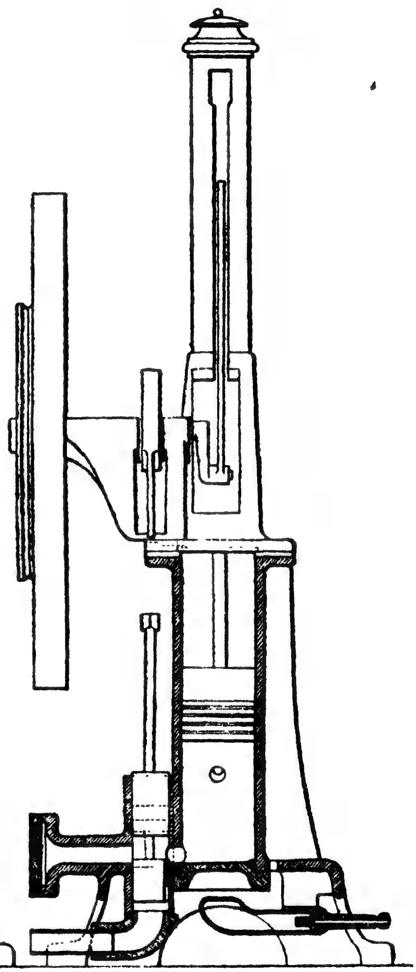
continuously, is to relight the other when it is blown out. The crank shaft lies across the machine a considerable distance from its axis, the apparent irregularity of action of this arrangement being ingeniously taken advantage of.

The piston being at the bottom of its stroke, is at first raised by the energy stored in the fly-wheel and counterweight, and draws into the cylinder the mixture of air and gas through the valve. As soon as the bottom of the piston rises above the opening in the cylinder side, the jet outside explodes the mixture, and the explosion drives the piston to the top of its stroke. The pressure under the piston falls below that of the atmosphere, so that in its descending course the piston is at first driven downwards by the atmospheric pressure. The position of the connecting rod is so adjusted that it acts direct on the crank when the explosion drives the piston upwards.

1224.



1225.



Each of the two indiarubber gas pipes is carried through a spring closer, consisting of an upright bracket, having a thin flat spring carried up beside it, adjustable at the top by a nut. The pipe is held between the spring and the standard, and can be closed at will by turning the nut, which gives a very fine adjustment for regulating the quantity of gas passing.

The heat from the cylinder is got rid of by radiation, a number of radial ribs, Fig. 1226, being cast from the cylinder to increase its surface for this purpose.

The little apparatus shown below the cylinder in Fig. 1225 is a burner for heating it before starting. When working at its nominal power the engine should run from 100 to 120 revolutions a minute, for a much less power, say $\frac{1}{25}$ horse-power, at from 60 to 70 turns, $\frac{1}{8}$ to $\frac{1}{10}$ horse-power, at 130 to 145 turns a minute. To get the machine to work steadily at very small powers, it is necessary to carry a weighted cord round the flywheel, to act as a brake and increase the resistance.

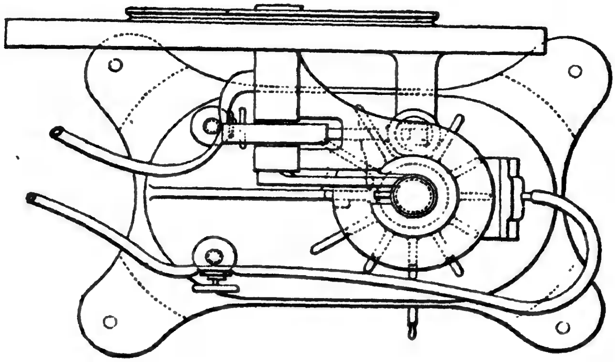
The machine, Fig. 1224, is said to use about 11·5 cub. ft. an hour, or about 145 cub. ft. a horse-power an hour.

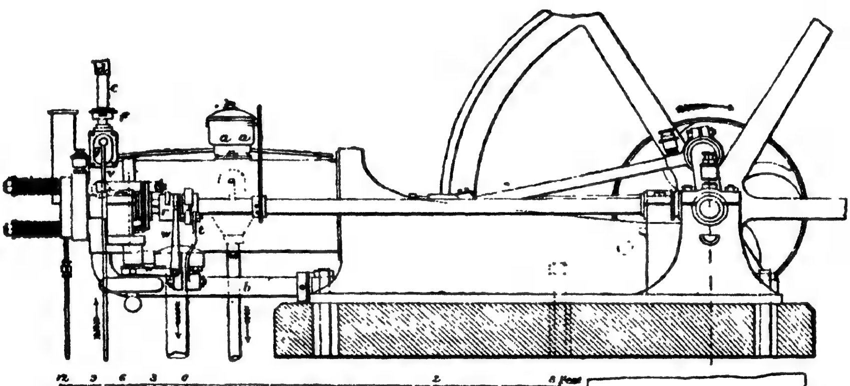
Figs. 1227 to 1229 are elevation, plan, and end elevation respectively of the Otto gas engine;

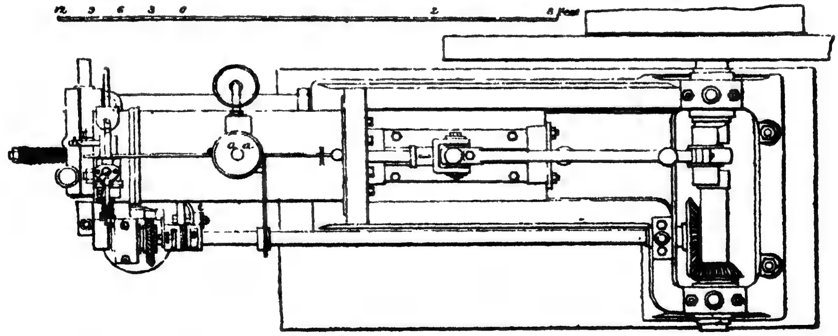
and Fig. 1230 is a section of the cylinder and valve on a somewhat larger scale. The cylinder, open at the front end, is fitted at back with a cover, A, carrying ports, and having a face against which a slide valve can work; this valve being kept in place by a separate cover C held against it by the two spiral springs, Figs. 1227, 1228.

When the piston is at the back of its stroke ready to draw in the explosive mixture, the valve is in such a position that the port, *j i*, in it makes communication between the passages *j* and *l* in

1226.





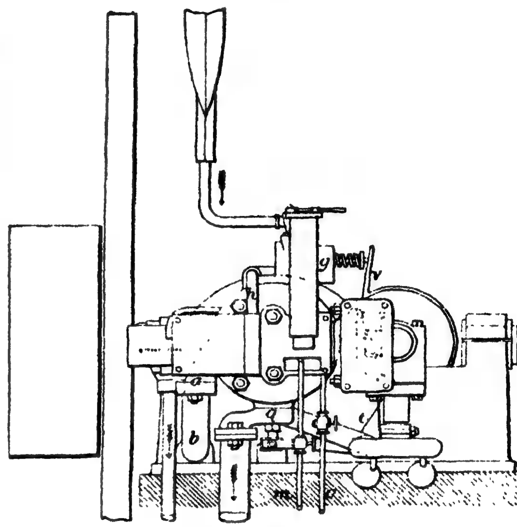


the cylinder A. When the piston moves, it draws in air through the valve from the opening *a* and the pipe *b*, and at the same time draws in gas through the small opening *k*, on the back of the valve, which is then opposite the passage B in the valve cover which communicates with the pipe *b*, Fig. 1229, above. The admission opening having been thus made and closed, the piston begins to return, and during its return the valve, moving continuously, keeps the port *l* closed. As the second stroke commences, the passage *n* comes opposite *l*, having been in communication with *m* and *o*. In the chamber *m* a small gas jet is always burning, fed by the pipe *m*, Fig. 1229, and through *o* a small stream of gas is allowed to pass. The passage *n* thus filled with gas from *o* ignited from *m* comes to *l*; this ignites the mixture in the cylinder and starts the stroke, while on the return stroke of the piston, the spent gases are discharged through the opening *q*, in the bottom of the cylinder.

It is necessary that the valve should make only one reciprocation for two strokes of the piston,

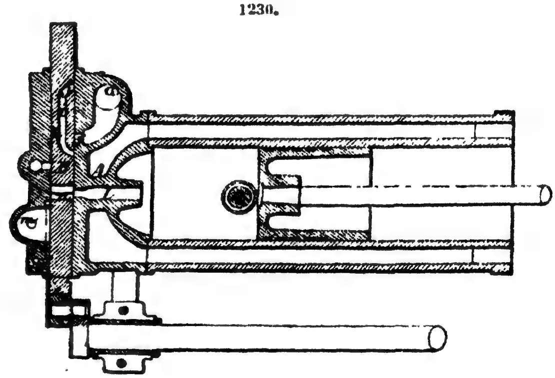
and for this purpose it is driven by a crank on the end of a counter shaft, which revolves with half the velocity of the crank shaft. The same shaft also serves to work the governor and two other valves. It carries a cam *r*, Fig. 1227, which by a lever *v* opens at intervals a valve *g*, closed again by a spring, which regulates the amount of gas admitted through *h* a stroke. A second cam *s*, by means of a lever *t* below the cylinder, opens and closes the exhaust valve *q*. The governor is worked from the counter shaft by bevel gearing ; it is merely a small loaded ball governor. By means of a lever *w* it controls the position of the cam *r* upon the shaft, so that if the speed of the engine exceeds a certain limit the gas admission valve *g* is left closed, and the engine runs on until sufficient of its stored-up energy is expended to bring the speed down to its proper level.

1229.



The cylinder is enclosed in a water jacket in order to prevent overheating. To ensure a circulation of water, it has been found sufficient to connect the top and bottom of the jacket with the top and bottom of a filled reservoir. The difference in the densities of the hot and cold water is enough to set up and maintain the requisite circulation. The water enters by one pipe, and returns to the reservoir by another, being cooled sufficiently by contact with the air to be used continuously. To avoid shock at exhaust, the hot gases are discharged through a pipe into a reservoir placed at a little distance, from which they pass into the atmosphere by a pipe and nozzle. The lubrication of the piston and valve is effected by the self-acting lubricator *a a*, driven from the counter shaft.

1230.



In Hock's petroleum engine the moving power is petroleum commingled with air, and ignited by the flame of a light hydrocarbon vapour behind the piston in a cylinder. The ignition is effected by gas produced by the engine itself, so that it is independent of any extraneous aid beyond the proper supply of its own fuel.

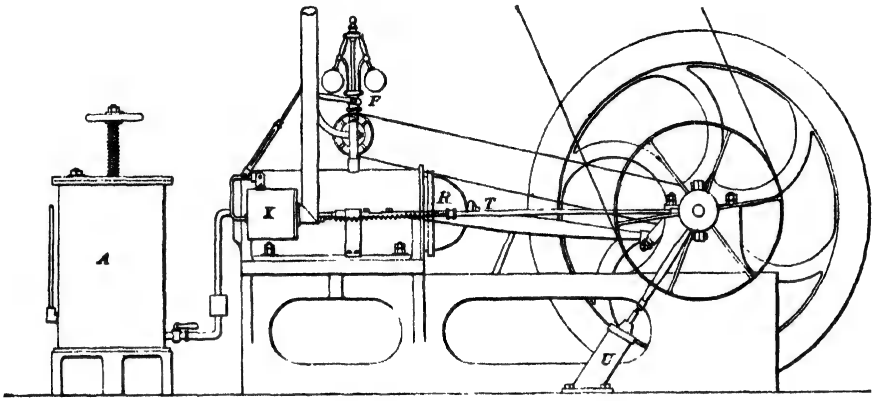
Figs. 1231 to 1235 show general and detail views of this engine, Fig. 1231 being a side elevation, Fig. 1232 a plan. Figs. 1233 to 1235 illustrate the principal details. A is the reservoir containing the petroleum used for feeding the engine. The level of the oil can be altered at will by raising or depressing the solid plunger B, by means of the screw C. The level of the petroleum can be ascertained by a gauge A. If the petroleum stands at a high level the engine does more, and if low, less work, with a proportionate consumption of material. The pipe E is screwed into the cover of the cylinder Z at one end, whilst at the other at B′ it is in connection with the petroleum reservoir. To the pipe E is attached a small chamber in which a valve E′ works automatically. The object of the bent tube F, with the valve F′, is to admit air to break up and disperse the jet of petroleum the moment it enters the cylinder.

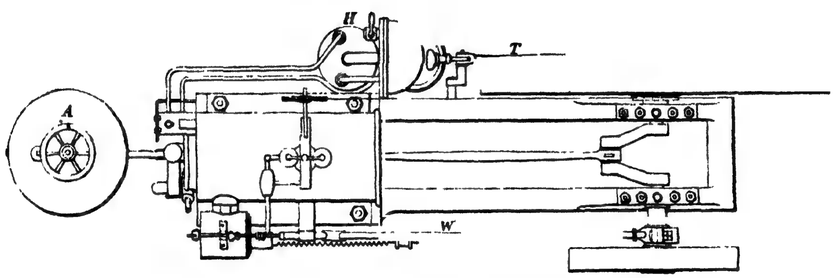
The ignition is effected by the aid of an air force-pump. A hollow hemispherical chamber R, Fig. 1234, made of indiarubber, is closed by an iron plate, in which is fitted a cock Q, in order to place the interior of the chamber in communication with the atmosphere when necessary. An opening in the plate is covered by an indiarubber valve S, opening inwards, and through which the chamber draws in atmospheric air, after the pressure of the buffer T, which is worked by an eccentric rod, has been removed. A pipe opening into the chamber, conducts the atmospheric air compressed by the buffer T, to the bottom of the apparatus for making the gas at H. This consists of an iron cylindrical vessel filled with naphtha. The compressed air being conducted through the pipe P to the bottom of the vessel H, passes upwards through the naphtha, and in this manner forms a combustible gas. This illuminating gas leaves the vessel H at J′, and is discharged at regular intervals in rapid succession into the atmosphere at J, to be ignited by the constant flame of the burner N′. This burner is fed by gas which is made in the apparatus H, and is delivered by the pipe K into the small gasholder M, proceeding thence to the burner by the pipe N. N″ is a screen of sheet iron which protects the flame from being extinguished. The horizontal flame from the burner J is intermittent, being expelled with greater or less force according to the pressure of

the buffer T on the hemispherical chamber, and the amount of pressure is dependent on the position of the buffer rod eccentric.

On the cylinder near the cover, Fig. 1235, is the valve chest X, containing two valves *b* and *c*, which are placed opposite each other, and both of which open inwards. The valve *c* serves for the

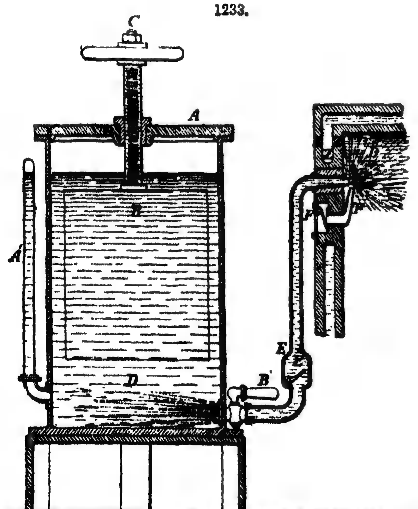
1231.



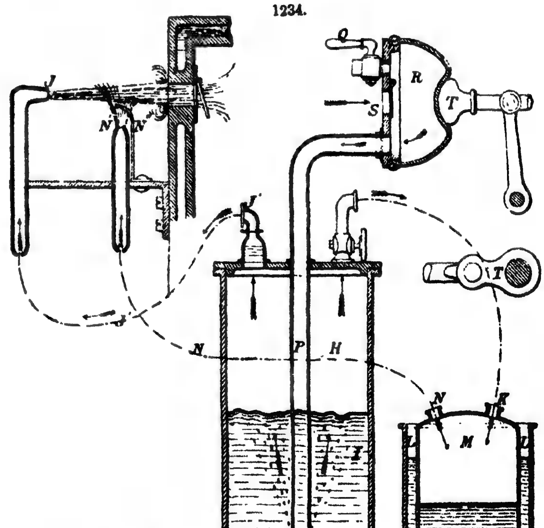


1232.

1233.



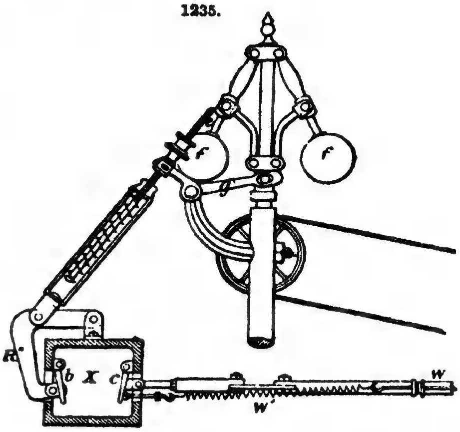
1234.



discharge, and allows the products of combustion to escape, by being pressed open by the eccentric rod W, while the piston in the cylinder moves backwards. After the gases have escaped, the spiral spring W' rapidly closes the valve again; a slide valve, however, might here be used. Covering the opening, in which is the valve *c*, is a tube whereby the products of combustion are carried off,

These gases pass away at a high temperature, and may be used for warming workshops by means of tubing. The air admission valve *b* regulates indirectly the quantity of petroleum, which is introduced into the cylinder at every travel of the piston; it is more or less weighted by means of a steel spiral spring, which is enclosed in a metal case. This spring is coiled around an iron rod, which has a button at its lower end to retain the spring. The upper end of this rod forms a screw, by means of which and a nut the tension of the spring is regulated. As the introduction of the liquid petroleum, as well as of the air, into the cylinder takes place through the superior pressure of the atmosphere respectively, owing to the vacuum produced by the moving forward of the piston in the cylinder, the quantity of petroleum introduced depends, in the first place, on the weight brought to bear on the air valve *b*. If there is no weight at all on the valve, the pistons will draw in air only, and no petroleum; should the weight on the valve be excessive, above one atmosphere, it will not open, and no air, except that admitted by the valve *c*, will enter, but there would be a great excess of petroleum in the cylinder.

1235.



The cylinder Z is double, having a water space around it, to which water is supplied by the circulating pump U, to prevent excessive heating. The circulating pump is not indispensable, as water for cooling may be applied in other ways. But the heating of the cylinder and of the piston to a temperature at which the lubricating oil burns must be prevented, in order to avoid a rapid wear of the engine.

In starting the engine, the flywheel is first moved, and the piston is travelled forward in the cylinder, when it would create a vacuum behind it, if the air valves *b*, Fig. 1235, and F', Fig. 1233, did not admit air, and the pipe E, Fig. 1233, petroleum in very small quantities at the same time. The petroleum, which is injected as a fine jet, becomes dispersed or formed into a fine spray, by the in-rush of air from the tube F nearly at right angles to it. When the piston has moved forward about a quarter of its travel, there is behind it a mixture of finely-divided partly-vaporized petroleum and atmospheric air. At this point the buffer strikes the elastic chamber R, in consequence of which a current of combustible gas darts out of the jet J, Fig. 1234, is ignited by the constantly burning flame at N', enters the cylinder, and ignites the mixture. The combustion takes place at a high temperature, and with proportionate pressure. All the valves opening inwards are closed by the explosion, the piston is pushed forward, completing its stroke, and thus taking up in the shape of work, a great portion of the heat produced. The backward travel of the piston is effected through the action of the flywheel. The same process is repeated in the next forward stroke, and the engine is thus set in motion. If it moves too quickly, the ball governor acts upon the valve *b*, through the spring, Fig. 1235, and reduces the weight on the valve. At the next stroke more air, and consequently less petroleum, enters the cylinder, and the speed slackens. The reverse of this takes place if the engine is running too slowly. If the cock Q on the elastic chamber is opened whilst the engine is in motion, the air which is in the chamber will not be forced into the gas-making apparatus H, but will pass into the air. In consequence of this no gas will escape at J, the explosive mixture in the cylinder will not be ignited, and the engine will stop after a few revolutions for want of impulse. The same effect will be produced if the cock B', Fig. 1233, is shut, as the supply of petroleum would then be stopped and air only would be admitted into the cylinder.

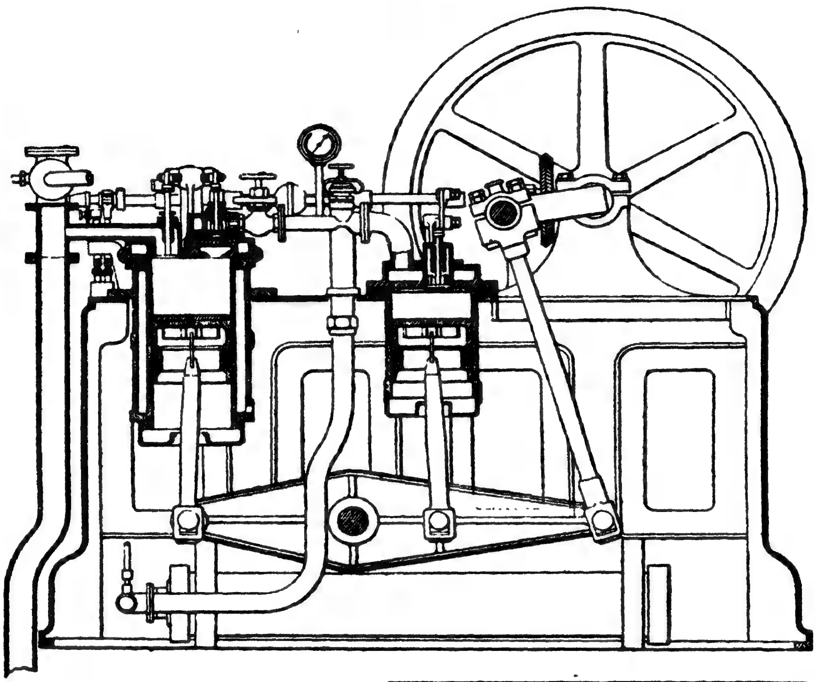
In Thomson, Sterne, and Co.'s carbon engine, of which Figs. 1236 and 1237 are sectional elevation and plan, the bed plate of the machine consists of a deep hollow casting, into the top table of which two vertical cylinders are recessed. That to the left is the working cylinder, which is 8 in. in diameter with 12 in. stroke, while the other is the air pump, and is 8 in. in diameter with a 6 in. stroke. A pipe forms the connection between the air pump and working cylinder. The air is first compressed in the air pump, whence it is delivered through this pipe past an inlet valve into the working cylinder. On its way to the latter the air passes through perforated brass discs, having wire gauze placed between them, just above the entrance to the working cylinder. An annular space, Fig. 1236, just above these discs is packed with felt, and into this the hydrocarbon oil is pumped from a store tank by a small pump, and worked by an eccentric on the shaft by which the valves are operated. From the felt the oil is transferred to the discs, over which it is distributed. On passing through the discs the air becomes charged with hydrocarbon vapour, to the extent necessary to effect its complete combustion in the working cylinder.

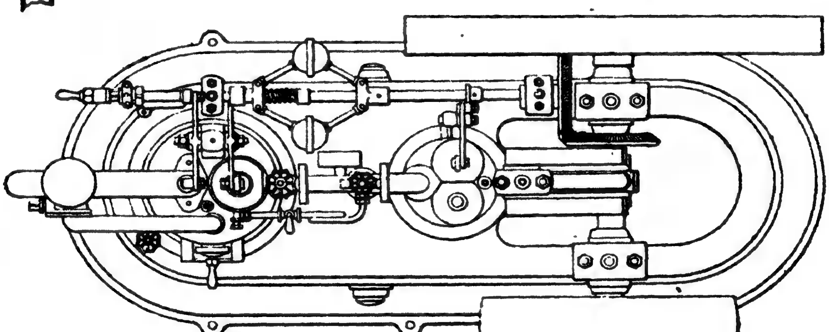
In the chamber just below the discs is a flame, which is caused by igniting this inflammable mixture at that point before starting the engine. This flame is constantly maintained during working, each additional charge of saturated air is ignited as it passes this point, and then acts on the piston. The engine is single-acting, fitted with a flywheel, the piston receiving its impulse on the down stroke, at the end of which the exhaust valve in the top of the cylinder is opened, and is closed just before the piston finishes its up stroke.

At the lower part of the engine are two malleable iron tubes which form air reservoirs. One of these is a regulator, used for preventing too great variations in the air pressure, whilst the other contains a store of highly compressed air, which can be used for starting the engine instead of giving the flywheel a turn.

The connecting rods are coupled to the working piston and air-pump piston by thin plates, which permit of the necessary flexibility, there being no joints at these points. Motion is communicated to the crank shaft through a beam mounted within the engine frame, the valves of the working cylinder and air pump are operated from a shaft, which is coupled to the crank shaft by bevel gear, and which carries the governor. The opening of the valve which admits air into the working cylinder, is effected by a cam on the sliding sleeve of the governor.

1236.





1237.

In external appearance the engine resembles a small horizontal engine. The cylinder is single-acting, open at the front end, and so arranged that it only completes its cycle of operations once in two complete double strokes. The piston in moving forward draws into the cylinder a mixture of air and coal gas, the latter in measured quantity; returning, it compresses this mixture into little more than one-third of its volume, as drawn in at atmospheric pressure; these two operations take up one complete double stroke. As the piston is ready to commence the next stroke the burnt gases are expelled from the cylinder, and the whole made ready to start afresh. Work is actually being done on the piston, therefore, only during one-quarter of the time it is in motion, the gearing, as well as the work driven, being carried forward by the flywheel during the rest of the time.

EXPLOSIVES.

A knowledge of the properties and respective values of the various kinds of explosives, is essential to every engineer who has at any time to employ blasting in his practice, and this is all the more necessary as there is considerable danger, and oftentimes great waste, in dealing with substances of the character in question, of whose particular nature we are partially ignorant. It should be borne in mind that an explosive mixture is a combination of certain chemical substances, capable of

being suddenly transformed into gas by the application of heat. Hence an explosion is a sudden evolution of gases accompanied by pressure, the intensity of the pressure depending upon the nature of the mixture.

In the combustion of gunpowder, the elements of which it is composed combine to form, as gaseous products, carbonic acid, carbonic oxide, nitrogen, sulphuretted hydrogen, and marsh gas or carburetted hydrogen, and, as solid products, sulphate, hyposulphite, sulphide, and carbonate of potassium. Theoretically, some of these compounds should not be produced; but experiment has shown that they are. It has also been ascertained that the greater the pressure, the higher is the proportion of carbonic acid produced, so that the more work the powder has to do, the more perfect will be the combustion, and, consequently, the greater will be the force developed. Hence over-charging is not only very wasteful of the explosive, but the atmosphere is more noxiously fouled thereby. The same remark applies even more strongly to gun-cotton and the nitro-glycerine compounds.

The careful experiments of Noble and Abel have shown that the explosion of gunpowder produces about 57 per cent. by weight of solid matters, and 43 per cent. of permanent gases. The solid matters are, at the moment of explosion, in a fluid state. When in this state they occupy 0·6 of the space originally filled by the gunpowder, consequently the gases occupy only 0·4 of that space. These gases would, at atmospheric pressure and 32° F. temperature, occupy a space 280 times that filled by the powder. As they are compressed into 0·4 of that space, they would give a pressure of $\frac{280}{0 \cdot 4} \times 15 = 10{,}500$ lb., or about 4·68 tons to the sq. in. But a great quantity of heat is liberated in the reaction, and this heat will enormously increase the tension of the gases. The experiments of Noble and Abel showed that the temperature of the gases at the instant of explosion is about 4000° F. Thus the temperature of $32° + 461° \cdot 2 = 493 \cdot 2$ absolute, has been raised $\frac{4000}{493 \cdot 2} = 8 \cdot 11$ times, so that the total pressure of the gases will be $4 \cdot 68 \times 8 \cdot 11 = 37 \cdot 9$ tons to the sq. in. And something near this pressure was, in the experiments referred to, generally indicated by the crusher gauge; although gunpowder exploded in a space which it completely fills, has developed a force estimated as giving a pressure of about 42 tons to the sq. in.

Unfortunately no complete experiments have hitherto been made to determine the absolute force developed by gun-cotton and nitro-glycerine. We are, therefore, unable to estimate the pressure produced by the explosion of those substances, or to make an accurate evaluation of their strength relatively to that of gunpowder. It should, however, be borne in mind that a correct estimate of the pressure produced to the sq. in. would not enable us to make a full comparison of the effects they were capable of causing. For though, by ascertaining that one explosive gives twice the pressure of another, we learn that one will produce twice the effect of another; yet it by no means follows from that fact that the stronger will produce no more than twice the effect of the weaker. The rending effect of an explosive depends, in a great measure, on the rapidity with which combustion takes place. The force suddenly developed by the decomposition of the chemical compounds acts like a blow, and the same force, when applied in this way, will produce a greater effect than when it is applied as a gradually increasing pressure. But some calculations have been made, and some experiments carried out, which enable us to form an approximate estimate of the relative strength of these explosive substances.

Roux and Sarrau give the following as the result of their investigations, derived from a consideration of the weight of the gases generated and of the heat liberated;—

TABLE I.—RELATIVE STRENGTH OF EXPLOSIVES.

Substance.	Relative Weight of Gases.	Heat in Units liberated from 1 lb.	Relative Strength.
Gunpowder	0·414	1316	1·00
Gun-cotton	0·850	1902	3·00
Nitro-glycerine	0·800	3094	4·80

In Table I. the substances are simply exploded, and the strength of gunpowder is taken as unity. The relative strength is that due to the volume of the gases and the heat, no account being taken of the increased effect due to the rapidity of the explosion.

Alfred Nobel has essayed to appreciate the effects of these different explosives by means of a mortar loaded with a 32-lb. shot and set at an angle of 10°, the distances traversed by the shot being taken as the results to be compared. Considered, weight for weight, he estimates as follows the relative strengths of the substances compared, gunpowder being again taken as unity;—

Gunpowder	1·00	Dynamite	2·89
Gun-cotton	2·84	Nitro-glycerine	4·00

The relative strength, bulk for bulk, is, however, of greater importance in rock blasting. This is easily computed from the foregoing table and the specific gravity of the substances, which is 1·00 for gunpowder and compressed gun-cotton, 1·60 for nitro-glycerine, and 1·65 for dynamite. Compared in this way, bulk for bulk, these explosives range as follows;—

Gunpowder	1·00	Dynamite	4·23
Gun-cotton	2·57	Nitro-glycerine	5·71

Hence, for a given height of charge in a bore-hole, gun-cotton exerts about 2½ times the force of gunpowder, and dynamite about 4½ times that force.

The oxygen required for the combustion of the carbon in gunpowder is stored up in the saltpetre. So long as the saltpetre remains below a certain temperature, it will retain its oxygen; but when that temperature is reached, it will part with that element. To fire gunpowder, heat is therefore made use of to liberate the oxygen, which at once seizes upon the carbon with which it is in presence. The means employed to convey heat to an explosive have been described in the article on Blasting. It is necessary to apply heat to one point only of the explosive; it is sufficient if it be applied to only one grain. That portion of the grain which is thus raised in temperature begins to burn, as it is commonly expressed, that is, this portion enters at once into a state of combustion, the saltpetre giving up its oxygen, and the liberated oxygen entering into combination with the carbon. The setting up of this action is called ignition. The hot gases generated by the combustion set up, ignite other grains surrounding the one first ignited; the gases resulting from the combustion of these ignite other grains; and, in this way, ignition is conveyed throughout the mass. Thus the progress of ignition is gradual. But though it takes place, in every case, gradually, if the gases are confined within the space occupied by the powder, it may be extremely rapid. It is easy to see that the gases evolved from a very small number of grains are sufficient to fill all the interstices, and to surround every individual grain of which the charge is composed. But besides this ignition from grain to grain, the same thing goes on from the outside to the inside of each individual grain, the grain burning gradually from the outside to the inside in concentric layers. The successive ignitions in this direction, however, of layer after layer, are usually described as the progress of combustion. Thus the time of an explosion is made up of that necessary for the ignition of all the grains, and of that required for their complete combustion.

The time of ignition is determined in a great measure by the proportion which the interstices, or empty spaces between the grains, bear to the whole space occupied by the powder. If the latter be in the form of an impalpable dust, ignition cannot extend throughout the mass in the manner we have described; but we shall have merely combustion proceeding from grain to grain. If, on the contrary, the powder is in large spherical grains or pellets, the interstices will be large, and the first gases formed will flush through these, and ignite all the grains one after another with such rapidity that ignition may be regarded as simultaneous. Thus the time of ignition is shortened by increasing the size of the grains and approximating the latter to the spherical form.

But the time of combustion is determined by conditions contrary to these. As combustion proceeds gradually from the outside to the inside of a grain, it is obvious that the larger the grain is, the longer will be the time required to burn it in. Also it is evident that if the grain be in the form of a thin flake, it will be burned in a much shorter time than if it be in the spherical form. Thus the conditions of rapid ignition and rapid combustion are antagonistic. The minimum time of explosion is obtained when the grains are irregular in shape, and only sufficiently large to allow a fairly free passage to the hot gases. There are other conditions which influence the time of combustion; among them is the density of the grain. The denser the grain, the greater is the quantity of material to be consumed. But besides this, combustion proceeds more slowly through a dense grain than through an open one. The presence of moisture also tends to retard combustion.

The progress both of ignition and of combustion is accelerated, not uniform. In proportion as the grains are ignited, the gases evolved increase in volume, and as the progress of combustion continues to generate gases, the tension of these increases, until the pressure rises as high as 42 tons to the square inch. As the pressure increases, the hot gases are forced more and more deeply into the grains, and combustion, consequently, proceeds more and more rapidly.

By detonation is meant the simultaneous breaking up of all the molecules of which the explosive substance is composed. Properly the term is applicable to the chemical compounds only. But it is applied to gunpowder to denote the simultaneous ignition of all the grains. The mode of firing by detonation is very favourable to the rending effect required of blasting powder, since it reduces to a minimum the time of explosion. It is brought about, in all cases, by means of an initial explosion. The detonator, which produces this, consists of an explosive that is quick in its action, contained within a case sufficiently strong to retain the gases until they have acquired a considerable tension. When the case bursts, this tension forces them instantaneously through the interstices of the powder, and so produces simultaneous ignition. A pellet of gun-cotton, or a cartridge of dynamite, the latter especially, makes a good detonator for gunpowder. Fired in this way, very much better effects may be obtained from gunpowder than when fired in the usual manner. Indeed, in many kinds of rock, more work may be done with it than with gun-cotton or with dynamite.

The action of a detonator upon a chemical compound is different. In this case, the explosion seems to be due more to the vibration caused by the blow than by the heat of the gases from the detonator. Probably both of these causes operate in producing the effect. Under the influence of the explosion of the detonator, the molecules of a chemical compound, like nitro-glycerine, are broken up so nearly simultaneously, that no tamping is needed to obtain the full effect of the explosion. Dynamite is always, and gun-cotton is usually, fired by means of a detonator. A much larger quantity of explosive is needed to detonate gunpowder than is required for dynamite, or gun-cotton, since, for the former explosive, a large volume of gases is requisite. Dynamite detonators usually consist of from six to nine grains of fulminate of mercury contained in a copper cap. Gun-cotton detonators are similar, but have a charge of from ten to fifteen grains of the fulminate. An insufficient charge will only scatter the explosive instead of firing it, if it be unconfined, and only explode it without detonation, if it be in a confined space.

The combustion of gunpowder being gradual and comparatively slow, its action is rending and projecting rather than shattering. This constitutes one of its chief merits for certain purposes.

In many quarrying operations, for instance, the shattering action of the chemical compounds would be very destructive to the produce. In freeing blocks of slate, or of building stone, a comparatively gentle lifting action is required, and such an action is exerted by gunpowder. Moreover, this action may be modified by using light tamping, or by using no tamping, a mode of employing gunpowder often adopted in slate quarries. The effect of the violent explosives cannot be modified in this way.

Gunpowder is injured by moisture. A high degree of moisture will destroy its explosive properties altogether, so that it cannot be used in water without some protective covering. Even a slight degree of moisture, as little as one per cent. of its weight, materially diminishes its strength. For this reason, it should be used, in damp ground, only in cartridges. This is, indeed, the most convenient and the most economical way of using gunpowder in all circumstances. It is true that there is a slight loss of force occasioned by the empty space around the cartridge, in holes that are far from circular in shape. But at least as much will be lost without the cartridge from the moisture derived from the rock, even if the hole is not wet. But in all downward holes, the empty spaces may be more or less completely filled up with dry loose sand.

The products of the explosion of gunpowder are partly gaseous, partly solid. Of the former, the most important are carbonic acid, carbonic oxide, and nitrogen. The sulphuretted and the carburetted hydrogen are formed in only small quantities. The carbonic oxide is a very noxious gas; but it is not formed in any considerable quantity, except in case of overcharging. The solid products are compounds of potassium and sulphur, and potassium and carbon. These constitute the smoke, the dense volumes of which characterize the explosion of gunpowder. This smoke prevents the immediate return of the miner to the working face after the blast has taken place.

The combustion of gun-cotton takes place with extreme rapidity, in consequence of which its action is very violent. Its effect is rather to shatter the rock than to lift it out in large blocks. This quality renders it unsuitable to many quarrying operations. In certain kinds of weak rock, its disruptive effects are inferior to those produced by gunpowder. But in ordinary mining operations, where strong tough rock has to be dealt with, its superior strength and quickness of action, particularly the latter quality, produce much greater disruptive effect than can be obtained from gunpowder. Moreover, its shattering action tends to break up into small pieces the rock dislodged, whereby its removal is greatly facilitated.

Gun-cotton may be detonated when in a wet state by means of a small quantity of the dry material. This allows the substance to be used in a wet hole without protection, and conduces greatly to the security of those who handle it. When in the wet state, it is uninflammable, and cannot be exploded by the heaviest blows. Only a powerful detonation will bring about an explosion in it when in the wet state. It is, therefore, for safety, kept and used in that state. Since it is insensible to blows, it may be rammed tightly into the bore-hole, so as to fill up all empty spaces. The primer of dry gun-cotton, however, which is to detonate it, must be kept perfectly dry, and handled with caution, as it readily detonates from a blow. Gun-cotton, when ignited in small quantities in an unconfined space, burns fiercely, but does not explode.

The products of the combustion of gun-cotton are;—Carbonic acid, carbonic oxide, water, and a little carburetted hydrogen or marsh gas. On account of the insufficiency of oxygen, already pointed out, a considerable proportion of carbonic oxide is formed, which vitiates the atmosphere into which it is discharged. Overcharging, as in the case of gunpowder, causes an abnormal quantity of the oxide to be formed.

As combustion takes place more rapidly in nitro-glycerine than in gun-cotton, the effects of dynamite are more shattering than those of the latter substance. Gun-cotton holds, indeed, a mean position in this respect between dynamite, on the one hand, and gunpowder on the other. Dynamite is, therefore, even less suitable than gun-cotton for those uses which are required to give the produce in large blocks. But in very hard and tough rock, it is considerably more effective than gun-cotton, and, under some conditions, it will bring out rock which gun-cotton fails to loosen.

Dynamite is unaffected by water, so that it may be used in wet holes; indeed, water is commonly used as tamping, with this explosive. In upward holes, where water cannot, of course, be used, dynamite is generally fired without tamping, its quick action rendering this unnecessary.

The pasty form of dynamite constitutes a great practical advantage, inasmuch as it allows the explosive to be rammed tightly into the bore-hole so as to fill up all empty spaces and crevices. This also renders it very safe to handle, as blows can hardly produce sufficient heat in it to cause explosion. If a small quantity of dynamite be placed upon an anvil and struck with a hammer, it explodes readily; but a larger quantity so struck does not explode, because the blow is cushioned by the kieselguhr. If ignited in small quantities in an unconfined space, it burns quietly without explosion.

If dynamite be much handled out of the cartridges, it causes violent headaches; and the same effect is produced by being in a close room with it in the unfrozen state.

Dynamite possesses the disadvantage of freezing at a comparatively high temperature. At about 40° F. the nitro-glycerine solidifies, and the dynamite becomes chalky in appearance. In this state it is exploded with difficulty, and, consequently, it has to be thawed before being used. This may be safely done by leaving it a short time in a vessel which is immersed in hot water; performed in any other way the operation is dangerous.

The products of the combustion of dynamite are carbonic acid, carbonic oxide, water, and nitrogen. As, however, there is more than a sufficiency of oxygen in the compound, but little of the oxide is formed when the charge is not excessive. If, therefore, dynamite be properly detonated by using a detonator of sufficient strength, and placing it well into the primer, and overcharging be avoided, its explosion will not greatly vitiate the atmosphere. But if it be only partially detonated hypo-nitric fumes are given off, which have a very deleterious effect upon the health.

Table II. shows the temperatures at which the commonly used compounds explode.

TABLE II.—FIRING POINTS OF EXPLOSIVES.

	When slowly Heated.	When suddenly Heated.
Gunpowder	..	from 500° to 540°
Gun-cotton, Cotton powder	360°	482°
Kieselguhr dynamite, Lithofracteur	356°	446°
Cellulose dynamite	342°	446°

From Table II. it will be seen that cotton powder explodes at the same temperatures as gun-cotton, and lithofracteur at the same temperatures as kieselguhr dynamite.

To furnish the oxygen which is wanting, gun-cotton has sometimes incorporated with it a certain proportion of nitrate of potash, or of nitrate of baryta. This compound, which, it will be observed, is at once a chemical compound and a mechanical mixture, is known as nitrated gun-cotton.

The explosive which is now well known as tonite or cotton powder, is a variety of nitrated gun-cotton. It is produced in a granulated form, and is compressed into cartridges of various dimensions to suit the requirements of practice. The convenient form in which tonate is made up, ready to the miner's hand, has greatly contributed towards bringing it into favour. But irrespective of this, the fact of its being so higly compressed as to give it a density equal, or nearly equal, to dynamite gives it a decided advantage over the other nitro-cotton compounds, as they are at present used.

In Schultze's powder, the cellulose is obtained from wood. The wood is first sawn into sheets, about $\frac{1}{12}$ in. thick, and then passed through a machine, which punches it up into grains of a uniform size. These are deprived of their resinous matters by a process of boiling in carbonate of soda, and are further cleansed by washing in water, steaming, and bleaching by chloride of lime. The grains, which are then pure cellulose, are converted into nitro-cellulose in the same way as cotton, by being treated with a mixture of nitric and sulphuric acids. The nitro-cellulose thus produced is subsequently steeped in a solution of nitrate of potash. Thus the finished compound is similar in character to nitrated gun-cotton.

Lithofracteur is a nitro-glycerine compound in which a portion of the base is made explosive. In dynamite, the base, or absorbent material, is, as we have said, a siliceous earth, called "kieselguhr"; but in addition to kieselguhr, a mixture of nitrate of baryta and charcoal, a kind of gunpowder, is introduced. The object of employing this explosive mixture is to increase the force of the explosion, the kieselguhr being an inert substance. Obviously this object would be attained if the explosive mixture possessed the same absorbent power as the kieselguhr. But unfortunately it does not, and, as a consequence, less nitro-glycerine is used. Thus what is gained in the absorbent is lost in the substance absorbed. The composition of lithofracteur varies somewhat; but in general its ingredients are the following;—

Nitro-glycerine	32·50
Nitrate of baryta	16·40
Charcoal	2·85
Sulphur	25·75
Kieselguhr	22·50
	100·00

In Germany, gun-cotton is used as an absorbent for nitro-glycerine, the compound being known as Cellulose dynamite. It is chiefly used for primers to explode frozen dynamite. It is more sensitive to blows than the kieselguhr dynamite.

As to the quantity which is required for a given blast, theoretically the force due to the expansion of the gases is exerted equally in all directions. Consequently, the surrounding mass subjected to this force will yield, if it yield at all, in its weakest part, that is, in the part which offers least resistance. The line along which the mass yields, or line of rupture, is called the line of least resistance, and is the distance traversed by the gases before reaching the surface. When the surrounding mass is uniformly resisting, the line of least resistance will be a straight line, and will be the shortest distance from the centre of the charge to the surface. Such, however, is rarely the case, and the line of rupture will in most instances be an irregular line, often much longer than that from the centre direct to the surface. Hence in blasting there will be two things to determine, the line of least resistance, and the quantity of powder, or other explosive, requisite to overcome the resistance along that line. For it is obvious that all excess of powder is waste; and, moreover, as the force developed by this excess must be expended upon something, it will probably be employed in doing mischief Charges of powder of uniform strength produce effects varying with their weight, that is, a double charge will move a double mass. And as homogeneous masses vary as the cube of any similar line with them, the general rule is established, that charges of powder to produce similar results, are to each other as the cubes of the lines of least resistance. Hence when the charge requisite to produce a given effect in a particular substance has been ascertained by experiment, that necessary to produce a like effect in a given mass of the same substance may be readily determined. As the substances to be acted upon are various, and differ in tenacity in different localities, and as, moreover, the quality of powder varies greatly, it will be

necessary, in undertaking blasting operations, to make experiments in order to determine the constant which should be employed in calculating the charges of powder. In practice, the line of least resistance is taken as the shortest distance from the centre of the charge to the surface of the rock, unless the existence of natural divisions shows it to lie in some other direction; and, generally, the charge requisite to overcome the resistance will vary from $\frac{1}{15}$ to $\frac{1}{35}$ of the cube of the line, the latter being taken in feet and the former in pounds. Thus, suppose the material to be blasted is chalk, and the line of resistance 4 ft., the cube of 4 is 64, and taking the proportion for chalk as $\frac{1}{30}$, we have $\frac{64}{30} = 2\frac{2}{15}$ lb. as the charge necessary to produce disruption.

If dynamite be used, and we assume it to be four times as strong as common black powder, of course only one-fourth of this quantity will be required. Also if gun-cotton, or cotton powder, be used, and we assume its strength to be three times that of black powder, one-third only will be needed. Again, if carefully prepared extra-strong mining powder fired by a detonator be employed, we may assume it to be twice as strong as common black powder fired by the ordinary means, and consequently we shall need only one-half the quantity indicated by the formula.

It is neither practicable nor desirable that such calculations and measurements as these should be made for every blast; their practical value lies in this, namely, that if the principles involved in them be clearly understood, the blaster is enabled to proportion his charges by sight to the resistance to be overcome, with a sufficient degree of precision. A few experiments in various kinds of rocks, followed by some practice, will enable a man to acquire this power.

As it is a common and a convenient practice to make use of the bore-hole as a measure of the quantity of explosives to be employed, André has calculated the following table;—

TABLE III.—QUANTITY OF EXPLOSIVE FILLING BORE-HOLES.

Diameter of the Hole.	Black Powder in 1 inch.	Gun-cotton in 1 inch.	Dynamite, or Tonite, in 1 inch.
in.	oz.	oz.	oz.
1	0·419	0·419	0·670
1¼	0·654	0·654	1·046
1½	0·942	0·942	1·507
1¾	1·283	1·283	2·053
2	1·675	1·675	2·680
2¼	2·120	2·120	3·392
2½	2·618	2·618	4·189
2¾	3·166	3·166	5·066
3	3·769	3·769	6·030

The quantity of explosive that a given piece of work will require is, however, so much a matter of local practical experience that such rules can only serve as approximations and as general guides. It is the practice in many districts to employ charges of explosives consisting of a bottoming of either dynamite or gun-cotton, and complete the charge with gunpowder, the effect being that the hole is fully bottomed, whilst the lifting action of the gunpowder is fully retained.

The storing of explosives is a matter which in England has to be done under license from the government, which specifies exactly the kind and the maximum quantity of explosives which may be kept in the magazine. Other regulations prevail elsewhere, but in any case a proper magazine should be provided, and no two explosives kept in the same box under any circumstance whatever, while particular care must be always exercised to see that the detonators for such explosives as require them be kept entirely apart until wanted for use.

FANS.

Fans are very convenient machines for producing a blast such as is required for furnaces, ventilation, and the like.

It is desirable that the blast for cupolas should be adequate in quantity and pressure for the perfect combustion of the fuel, but not greatly in excess of what is needed for that purpose; it should be delivered as free from moisture as possible, and in a perfectly uniform stream.

The pressure of blast required varies according to the nature of the fuel employed; it is seldom that a greater pressure than from 2 to 3 in. of mercury is necessary, and with soft coke a much lower pressure will suffice.

If only for the purpose of supplying perfectly dry air to the cupola, it would be advantageous to heat the blast on its way from the blowing engine or fan; but by still further raising the temperature of the blast by passing it through regenerative firebrick stoves, a considerable economy in fuel would be obtained a ton of iron melted, without any deterioration in its quality taking place. Blast heated in this manner can be readily brought to a temperature of 1300° F., or can easily be regulated to any lower temperature desired.

The blast may be obtained by means of either blowing engines, fans, or blowers, any one of which answers the purpose as to quality and quantity of air supplied; questions of cost and convenience, affect principally the selection of the power to be employed.

Sometimes manganese or other reagents are blown into the cupola, when the iron is required for chill castings; it will be easier to send these into the cupola by means of the blast cylinder than by a fan.

The supply of blast must be regulated as to intensity of pressure and quantity. If a cutting blast is employed of too high a velocity, it will blow away a considerable quantity of small unburnt fuel. If the blast is too soft or feeble, much of the fuel will be burnt without doing its duty; and

if the pressure is allowed to fall below a certain amount, the furnace would consume an almost unlimited amount of fuel, without at any part attaining the melting point of cast iron.

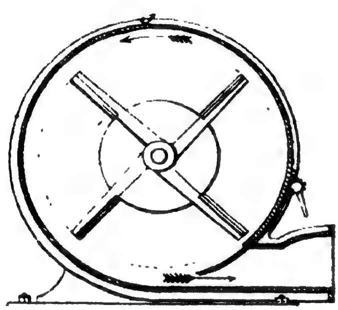
The quantity of blast necessary for any given cupola depends upon so many varying and disturbing elements, that experience and judgment must be mainly relied upon to estimate it. The effects of the blast are by no means difficult to observe; if there be too small a supply, imperfect combustion will result; if the supply is too large, the consumption of fuel will be increased; and much of its heat will be wasted, being carried away too rapidly through the cupola.

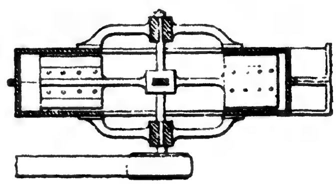
General Morin made some experiments on the duties of fans, and in one instance with blast of low pressure driven through long passages, he found that the useful effect of the fan was less than 0·07 of the steam power required to drive it.

The quality of the iron is much influenced by the quantity and intensity of the blast; if these or either of them are deficient, an inferior pig iron may give off sulphurous fumes, run thick and pasty, and make bad or inferior castings, while the same iron, with more favourable conditions as to blast, will probably lose much of its sulphur in the melting, and when tapped will turn out tolerably workable iron.

Any description of apparatus which will give the requisite volume and pressure of blast with regularity, can be adopted without in any way affecting the quality of the iron; but there are numerous other considerations to be studied as to the selection of the apparatus, such as first cost, economy in working, power required to drive, compared with duty in the shape of useful blast yielded, convenience for position, and safety.

Figs. 1238 and 1239 represent the ordinary form of common fans. In general they consist of a central spindle, upon which are hung from four to six arms meeting on an eye at the centre, through which the axle is passed, and by which they are fixed to the axle. Upon each of these arms a





blade generally is fixed by rivets or bolts; the assemblage of blades constitutes the propelling agents. To render them effectual they are encased in a round box, adapted to them, having a central opening each side, for the admission of air, and an opening in the circumference for the expulsion of air, with a short passage in continuation, to connect the air passages leading to the furnace. This case should be strong and heavy. By the rapid revolution of the blades upon this axle, a strong current sets in at the centre, and is propelled along the air passages to the cupola. The journals of the axles should be long, with the view of dispersing the great amount of friction to which they are subjected, by running in their bearing at such a high velocity as is usually communicated to the axle. Unless these parts be very well fitted, and the framework of the arms and blades perfectly balanced and firmly fixed upon the axle, the greatest difficulty is experienced in preventing the firing of the rubbing parts. It is easy to see that if there be a very slight want of equilibrium in the machine, or, in other words, if the centre of gravity of the moving parts does not lie in the axis of revolution, there will be an amount of centrifugal force created during revolution proportional to the eccentricity, which must be borne by the axle.

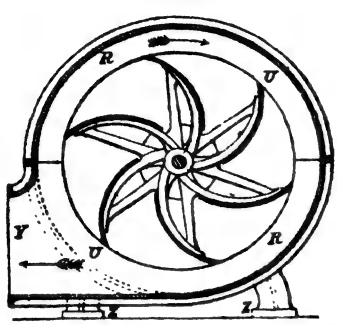
Lloyd's fan is shown in the vertical section, Fig. 1240, and plan, Fig. 1241. The outer case is cast in four parts, the two upper of which are bolted permanently together, and also the two lower. The horizontal joint through the centre admits of access to the internal parts without disturbing the foundations. S S are the bearings, and T the driving pulley. U is the internal revolving case, called the impeller, having sheet-iron discs V V fixed on the upper edges of the blades. X X are turned brass rings fixed on the discs, and fitted up against cast-iron rings bolted on the outer case, forming the centre opening through which the air enters the fan. Y is the discharge pipe, and L L the feet on which the machine stands, and by which it is bolted down to the foundations.

The difference between this fan and those of ordinary construction, consists in the form of the internal part U, which may be described as a revolving case, having six curved arms cast in one piece; on these are screwed curved sheet-iron blades, of the form shown in Fig. 1240, on the outer edge of which are fastened the sheet-iron discs V V, previously mentioned. The total area of the openings at the circumference, as also the total sectional area of the internal passages at any distance from the centre, is equal to the areas of the two central openings in the sides of the outer case.

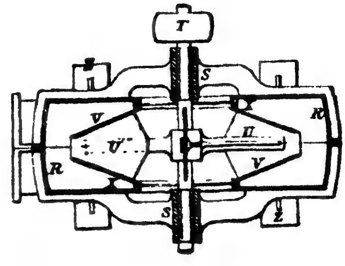
C. Schiele's fan has been very largely employed, and possesses a good many admirable features. It is simple in construction, requires very little to drive it, gives a good volume of draught relatively to its size, and is nearly noiseless in working. Referring to Figs. 1242 and 1243, it will be seen that Fig. 1243 is an edge view partly in section, and Fig. 1242 is a side view with one side of the casing removed to show the interior, with the revolving portion of the fan in its position.

A is a disc, on the periphery of which blades of the form represented in the figures are mounted. The blades are supported on their backs by means of ribs F, which, with the blades A, spring from the periphery of the disc A. This disc, with the blades and their supporting brackets, may be constructed even of the largest dimensions in one solid piece, either by casting or forging. B is the spindle on which the disc A is mounted; it runs in the bearings C, the spindle being of

1240.

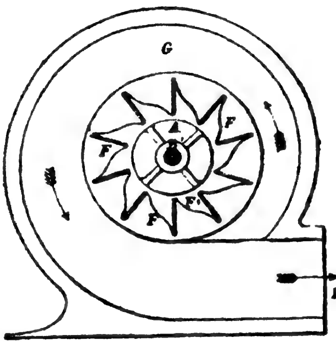


1241.

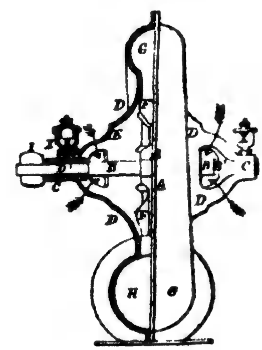


wrought iron, with cast-iron bushes; these bearings C are cast with and form part of the casing D, and on the top of each of them is an oil cup X, to hold oil to lubricate the spindle. The radius of disc A is larger than that of the central openings E, in the casings D, for the admission of air.

1242.



1243.



The casing D is formed of two halves similarly shaped, but so as to form right and left sides; each of these halves is of a curvilinear shape, curving towards the inside, and in the centre having the entrance openings E. The blades F are constructed of such a form, and in such proportion to the casing, that they gradually widen from the periphery of the disc to a point beyond the central openings in the casing. From this point they decrease in width, the casing narrows, and follows the contour of the casing; the tips of blades F terminating a short distance from the narrowest portion of the casing. Beyond the tips of the blades the casing slightly contracts for a short distance, so that the air of a slower speed, and which has gone beyond the blades F, is prevented from returning, and so impinging upon them.

Table I. gives a few particulars of the dimensions and work of these fans, as stated by the makers;—

TABLE I.—PARTICULARS OF SCHIELE'S FANS.

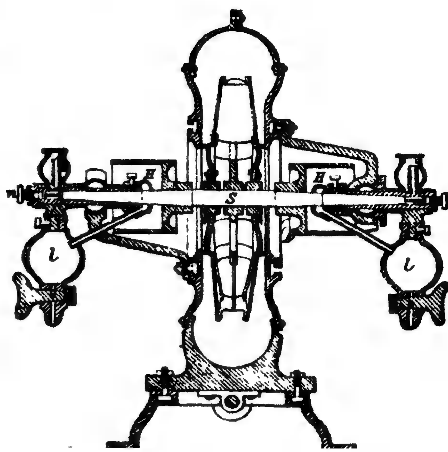
Diameter of Revolving Fan.	Tons Melted an Hour	Pulleys.	Diameter of Discharge.
inches		inches	inches
12	$1\frac{1}{4}$	3	6
16	$1\frac{3}{4}$	3	8
20	$2\frac{1}{2}$	4	10
30	5	6	14
40	10	9	18
50	20	12	24

Fig. 1244 is a cross section of Sturtevant's fan. Twelve vanes are rigidly supported by a similar number of spokes, radiating from an axis, and having conical annular discs mounted on the same axis, the fan being driven by two belts to prevent tendency to wobbling. The air enters

between the spokes around the axis, and is driven by the curved floats which span the space

whence it may be drawn by a faucet. The shaft S is supported in tubular bearings, sustained in brackets by means of ball joints, whereby the bearings are able to accommodate themselves to the shaft while in revolution. The oilers for the shaft are near the end, and have dripping wicks which feed the lubricant in regular quantity; the oil collectors H intercepting any superfluity, as already stated. The set screws *n n* afford means for adjusting the shaft lengthwise, so as to bring the wheel to its proper position in the case. Sturtevant's fan combines many of the features of both Lloyd's and Schiele's machines, its characteristic feature being the very long bearings given to the shaft; and although somewhat complicated in construction, it has been greatly used and deservedly popular in the United States.

1244.

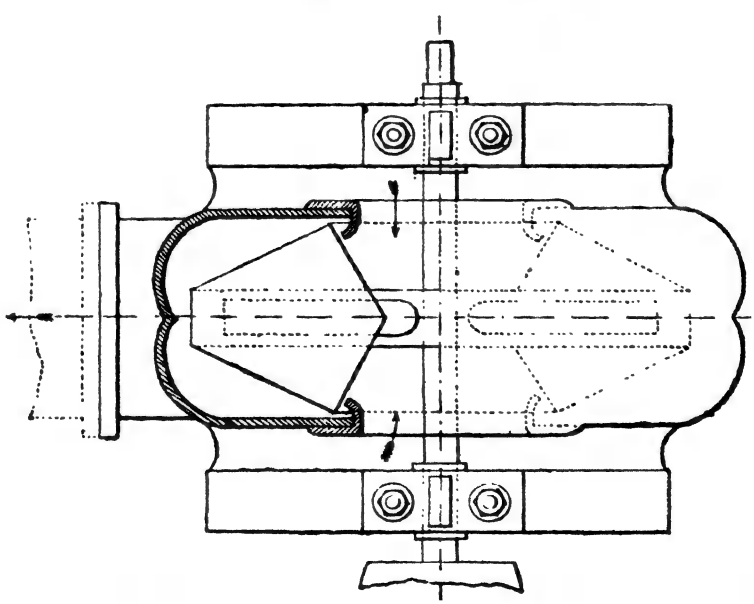


Figs. 1245, 1246 are half sectional plan, and half plan respectively of H. Aland's fan. It is of very strong and substantial construction, and differs from Lloyd's fan only in the arrangement of the intake, as will be evident by comparing Figs. 1241 and 1245; the vanes are so arranged that they act in effect as a double fan.

The spindles are made of steel, and work in long bearings. The discs also are made of the best charcoal iron. The tremor of the strap axis is confined to one casting, by the bearing standards being cast in one of the lower parts of the fan casing. The casing is also divided horizontally, to facilitate the operation of cleaning without disturbing the foundations.

In fan machinery, simple as it is, in some instances monthly and even weekly repairs are incurred, in consequence of the want of exact balance among the parts of the fan upon its axle. With careful management in the first construction, this source of annoyance may be entirely

1245. 1246.



removed. Another great fault consists of injudicious methods of bringing up the speed with too great rapidity, with a view to which it was certainly necessary to make use of as few intermediate shafts as possible, which of course requires that large pulleys shall drive proportionally smaller pulleys, than if the rate of the reduction of speed were more moderate. On the other hand, the experience of many engineers proves that by moderately attaining the speed, by the use of a greater number of intermediate belt pulleys, repairs of any importance are not incurred for months and even years. The great evil of too rapidly raising the speed is the aptitude of the belt to

slip upon the drums; for when slipping occurs, especially among the slower parts of the motion, the belt is subjected to sudden and violent strains, caused by its unequal hold upon the rim of the drum. The usual remedy for this state of things is to apply resin and pitch to the acting surface of the belt to give it a hold. But the best plan is to employ spur gear in the slower parts of the motion, and broad belts and pulleys of conveniently large diameters for the rest.

Properly constructed fans will work for many years without any perceptible wear, but in working they frequently make an unpleasant noise, especially when driven at high speeds.

The position of the fan in its case is preferably eccentric. The continually increasing winding passage, between the tips of the vanes and the chest, serves to receive the air from every point of the circumference of the fan, and produces a general accumulating stream of air to the exit pipe. The particles of air having passed the inlet opening, and entering on the heel of the vane, would retain the same circular path, were it not for the centrifugal force of the air, due to its weight and velocity, impelling them forward toward the tips of the vanes, and this continued action is going on, particle following particle, till they are ultimately thrown against the fan chest, and are impelled forward to the exit pipe. It is by this centrifugal action that the air becomes impelled and accumulated into one general stream. But there is a certain velocity of the tips of the vanes which best suits this action.

The pressure of the air in the pipe and chest, by the continuous rapid motion of the vanes, may be measured by a water or mercurial gauge attached to the blast chest.

It has been found that the greatest results are obtained, when the theoretical velocity and the velocity of the tips of the vanes are nearly equal.

Water is 827 times heavier than air, and mercury is 13·5 times heavier than water, or 11,164 times heavier than air; so that a column of mercury 1 in. in height would balance a column of air 11,164 in. or 930·3 ft. in height. A column of mercury of 30 in. is equal to a pressure of 15 lb. on a sq. in.; a column of mercury of 1 in. gives a pressure of $\frac{1}{2}$ lb. a sq. in. A column of mercury $\frac{1}{8}$ of an in. in height gives a pressure of 1 oz. a sq. in. Hence the height in inches of a column of mercury, equivalent to any given pressure or density, is found by dividing the density in ounces a sq. in. by 8.

The centrifugal force of air coincides with the results of the laws of falling bodies; that is, when the velocity is the same as the velocity which a body will acquire in falling the height of a homogeneous column of air, equivalent to any given density. Thus, taking the velocity, as obtained by the law of falling bodies, we find the centrifugal force or density of the air.

The velocity of the air and the diameter of the fan being given, the rule to find the centrifugal force is;—divide the velocity in feet a second by 4·01, and again divide the square of the quotient by the diameter of the fan in feet. This last quotient multiplied by 1·209, the weight in ounces of a cub. ft. of air at 60° F., is equal to the centrifugal force in ounces a sq. ft., which, divided by 144 is equal to the density of the air in ounces a sq. in.

To ascertain the theoretical velocity, the mouth of the discharge is closed, the velocity of the fan, merely keeping the air at a certain pressure a sq. in., when it is found that the tips of the vanes must move with nine-tenths of the velocity a body would acquire, in falling the height of a homogeneous column of air equivalent to the density. It is found that nine-tenths of the theoretical velocity is the most effectual speed, when the fan is not discharging air, but that the same proportion holds good also when the outlet pipe is open; that is, that the maximum effect of the fan is, when the vanes move with a velocity ranging from the theoretical velocity due to the density of the air, to nine-tenths of that velocity, the greatest quantity of air being discharged by the fan with the least expenditure of power. By making the top of the opening level with the tips of the vanes, the column of air has only a slight reaction on the vanes.

The degree of eccentricity of the fan in the casing that has been found to work well, is one-tenth of the diameter of the fan; that is, the space between the fan and the casing should increase from three-eighths of an inch at the top of the outlet to the delivery pipe, to one-tenth of the diameter of the fan at the point perpendicularly under the centre.

The main pipe from the casing may be not less than one and a quarter times the area of the delivery pipe, when under 100 ft. in length; for greater lengths it should be one and a half times the area of the delivery pipe.

From experiments made to establish the best proportions of inlet openings in the sides of the fan chest, and the suitable corresponding length of vanes, it was found that by impeding the free admission of air to the vanes a loss of power was occasioned. It was also found that the longer vane has a preponderating advantage over the shorter vane, in condensing air to the greatest density with the least proportion of power.

It will, therefore, be seen that the three most essential points in the economy of the fan, namely, the quantity and density of the air, and the expenditure of power, depend on the proportion of the length and width of the vanes, and the diameter of the inlet openings.

The width of the vanes, and their length, should be one-fourth of the diameter of the fan, and the diameter of the inlet opening in the sides of the fan casing should be one-half of the fan. Table II. gives the approximate dimensions of fans for obtaining the best results, varying from 3 to 6 ft. in diameter. The first six are the proportions for densities ranging from 3 to 6 oz. a sq. in., the second six are for higher densities.

Another variety of machines for blowing is that known as a pressure blower, which produces a blast having a positive force, and distinguished from a fan which does not produce a force blast. In this respect, a blower is analogous to cylinders used for producing blast. In either case, the air forced must find an outlet, or the machine stops. But a fan can run with the outlet obstructed or entirely closed, without being in the least impeded. In a pressure blower, in which the air is forced forward by a revolving vane or piston, the whole of the power applied, except the amount absorbed by the friction of the moving parts of the machine, is utilized in producing pressure; and should the outlet from the blower be throttled, the pressure of the blast will continue to

rise, until the limit of the driving power is reached, when the machine must stop. With a fan, however, the case is different; it must be run at a very high velocity to impart a sufficient momentum to air, a substance possessing only a very slight specific gravity; thus there is very considerable loss of power from the friction of the bearings, the journals of which run at such extreme speed, as well as from the power absorbed in continually changing the direction of the belts, which take short turns round very small pulleys, and but a portion of the air thus acted upon is really forced forward. Should the outlet from the fan be partially throttled, there will be but a very slight increase of pressure in the blast, while the fan continues to run at the same speed; and if the outlet be entirely closed, the fan will still continue running, absorbing much power, but producing no practical effect.

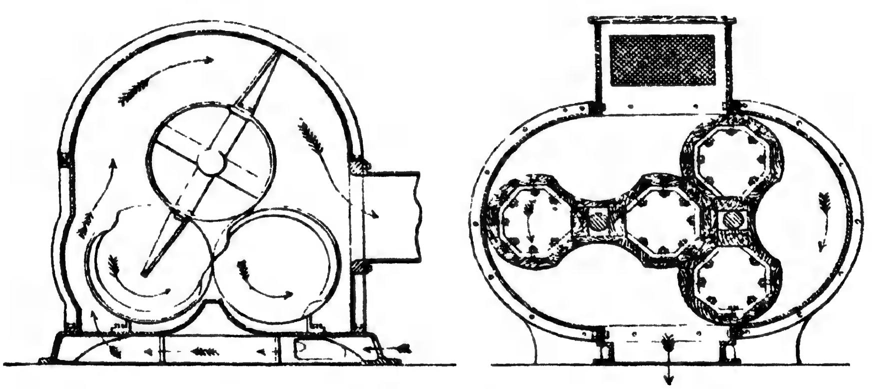
TABLE II.—DIMENSIONS OF COMMON FANS.

Diameter of Fan.		Width of Vane.		Length of Vane.		Diameter of Inlet Opening.	
ft.	in.	ft.	in.	ft.	in.	ft.	in.
3	0	0	9	0	9	1	6
3	6	0	10½	0	10½	1	9
4	0	1	0	1	0	2	0
4	6	1	1½	1	1½	2	3
5	0	1	3	1	3	2	6
6	0	1	6	1	6	3	0
3	0	0	7	1	0	1	0
3	6	0	8½	1	1½	1	3
4	0	0	9½	1	3½	1	6
4	6	0	10½	1	4½	1	9
5	0	1	0	1	6	2	0
6	0	1	2	1	10	2	4

The best known blower at present is Roots', an American invention, but largely used in England, and made here by Thwaites and Carbutt, of Bradford.

Roots' Blower, as arranged for foundry work, is shown in Figs. 1248, 1249. It has rotary pistons covered with wood lags, by which construction the pistons can be made lighter than cast-iron pistons, and thus take less power, run more quietly, and at twice the speed of the iron

1247.

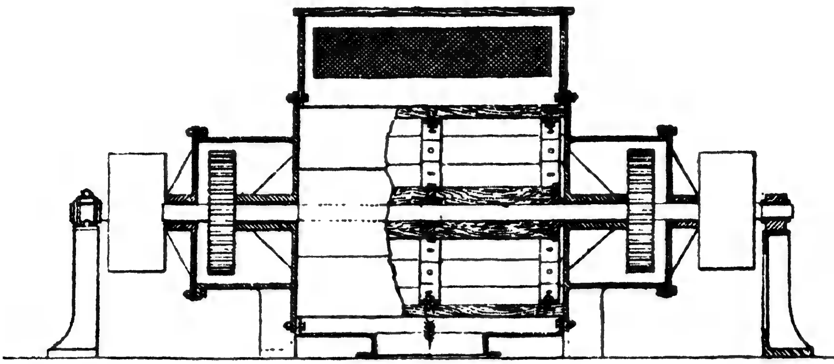


pistons. The thickness of a sheet of paper is the only clearance that is allowed, and, in order still further to reduce the clearance, a frictional composition is evenly applied with a brush, over the surface of the hollows of the rotary pistons, until every portion of the pistons is shown to be in contact.

The composition is of the consistency of ordinary paint, and also answers the purpose of preserving the wood. The wood used is the finest selected deal, free from knots, thoroughly seasoned and dried for three years. The lags are held upon malleable cast crossheads with bolts, which, for security, have the bolt ends riveted over the nuts. At the joints of the wood lags is inserted an iron tongue, which runs the whole length of the joints. The end plates are planed, and are provided with bosses, which are bored and fitted with hard gun-metal bushes, forming the bearings for the steel shafts. These gun-metal bearings are long, with considerable area of wearing surface, and can be easily replaced when worn out. The side plates of the casing are half cylinders, cast separately, planed on the flanges, bolted to form a circle, and then bored out as true as a steam-engine cylinder; the side plates and end plates are connected together with fixed bolts. The outlet branch is fixed in most cases at the bottom, and a perforated box cover is fixed at the top to admit the air, and to prevent anything else from entering the machine. At each end, outside the casing of the blower, is fixed a pair of accurately pitched spur wheels for gearing the two pistons together, which are covered in with iron boxes. Upon the iron box is fixed a cover plate, provided with gun-metal bushed bearings for the shafts, and outside of these covers are fixed the driving pulleys on one end of one shaft, and on the opposite end of the other shaft, a crossed and open belt from a

counter-shaft being used for driving; and outside the driving pulleys are fixed additional bearings to take the pull off the driving belts. All portions of these are made in duplicate, and the wood covered rotary pistons are correctly shaped to templates by a wood-planing machine. The original method of hand-shaping the revolver, which was at once tried, could not be depended upon to

1249.



produce the rotary pistons quickly and with sufficient accuracy. It appears that iron pistons, which frequently replace the wooden pistons in these blowers, are decidedly to be preferred if the blower is to be placed in a situation at all liable to dampness.

Table III. furnishes some interesting particulars as to the dimensions, work, dimensions of discharge pipes, and other details respecting Roots' blowers;—

TABLE III.—PARTICULARS OF ROOTS' ROTARY BLOWERS.

No. of Blower.	Melting Iron.			Approximate Horse-power.	Volumes of Blast, in Cubic Feet, delivered a Minute.	General Dimensions.									Approximate Weights.
	No of Revolutions a Minute.	Tons of Metal an Hour.	Adapted to Cupola Inside Lining.			Diameter of Pulleys.	Breadth of Pulleys.	Diameter of Delivery Orifice.	External Dimensions.						
									Length.		Breadth		Height.		
			in.			in.	in.	in.	ft.	in.	ft.	in.	ft	in.	cwt.
No. 2A	330	2½	24 to 30	2	1650	14	5	8	3	10	3	0	2	6	8½
„ 2	400	3	24 „ 30	2	2000	12	4	8	4	8	3	0	2	6	9½
„ 3	350	4½	30 „ 36	4	3000	14	5	10	5	8	3	0	2	8	12
„ 4	325	8	36 „ 48	6	4550	16	6	12	6	8	4	0	3	4	18
„ 5	320	12	48 „ 60	8	6400	18	7	14	7	10	4	0	3	6	23
„ 6	310	16	..	11	8680	20	9	18	8	0	5	0	4	0	30

It would appear that this machine, when fitted with wood pistons, is rather liable to be affected by variations in temperature, a matter which must be attended to in fixing the machine.

A blower of very ingenious construction is that invented by John G. Baker, of Philadelphia, and shown in section, Fig. 1247. It is already largely employed both in England and America, and promises to become a standard machine for foundry use. It consists, as will be seen from the figure, of three drums, the upper drum being furnished with two blades or vanes, passing alternately through wide openings made to receive them in the two lower drums. This blower is made entirely of iron, the cylindrical portion or case bored out and faced on the ends, the heads of the machine, or ends upon which the bearings are bolted, being also faced off true. The case is secured at the ends by bolts, and when in exact position the ends are dowelled, so that when the case is removed it can be returned to position without delay. The base is a solid casting faced on its upper side, and bolted firmly to the ends of the machine; the drums are each cast in one piece, turned truly, and balanced to ensure closeness, and at the same time to render them steady when running; the slots in the two lower drums extend throughout their entire length, and are made considerably wider than is needed for the passage of the wings, in order to ensure freedom in action, and prevent any danger of the wings striking against them when entering or leaving; the wings of the central drum are faced off and bolted on firmly; they are cast in the requisite form to ensure the greatest strength in proportion to their weight. As with other machines of this class, the bearings in general are made large, to secure extended bearing surface, and give the journals such a degree of strength as to prevent them springing, and to overcome rapid wear. To find the amount of power to be used with one of these machines, the following formula will be found useful, the quotient will be the actual horse-power, less the friction of the blower;—

Q = cubic feet of air delivered a minute.
P = pressure in ounces a square inch at blower.
H.P. = indicated horse-power required.

$2\,P \times \cdot 003$

Table IV. following relates to Baker's blowers, the sizes being those made by the Saville Street Foundry Company, Sheffield—

TABLE IV.—PARTICULARS OF BAKER'S BLOWERS.

No. of Blower.	Cubic Feet Displaced a Revolution.	No. of Revolutions a Minute.	Size of Cupola.	Iron Melted an Hour.	Diameter of Blast-pipe.
			in.	tons	in.
3	3	110	18 to 22	$\frac{3}{4}$	$6\frac{1}{4}$
"	"	180	"	$1\frac{1}{4}$	"
6	6	105	22 to 27	$1\frac{1}{4}$	8
"	"	150	"	2	"
9	9	100	27 to 30	2	$8\frac{1}{2}$
"	"	130	"	$2\frac{1}{2}$	"
13	13	95	30 to 34	$2\frac{1}{2}$	$9\frac{1}{2}$
"	"	120	"	$3\frac{1}{4}$	"
17	17	85	34 to 40	$3\frac{1}{4}$	$11\frac{1}{2}$
"	"	115	"	5	"
25	25	75	40 to 48	5	14
"	"	110	"	8	"
30	30	70	48 to 52	8	15
"	"	105	"	10	"
60	60	60	52 to 84	10	24
"	"	100	"	20	"

Blowers must be set on good solid stone foundations, to which they should be held by proper bolts, and care should be taken to set them level lengthwise. Too much stress cannot be laid upon the necessity for providing iron piping for the air-conducting pipes, and seeing that these, with the shut-off valves and connections, are perfectly tight. An escape valve may be fixed with advantage upon the air-pipes, to relieve the blower from too great an increase of pressure of air, caused by the closing of the shut-off valves while the machine is in operation.

It is to be regretted that no more definite and independent information is to be obtained, with regard to the superiority and relative advantages of the various pressure blowers in use, and of the comparative results obtained by such machines as applied to the foundry cupola, than that issued by their respective manufacturers. The subject has not yet received the attention it deserves at the hands of the ironfounder in England, nor have the results been so carefully worked out as in the United States of America, where the conditions of working are somewhat different; and it must be inferred from their tardy adoption, that the advantages offered have not been clearly understood or appreciated by the users here, many of whom have a strong preference for the fan.

There are, however, certain well-known advantages in their use as against the fan, which are more than sufficient to cover the increased cost of their adoption, and these will now be considered. The first great difference lies in the fact that the pressure blower is a positive or force blast, measuring accurately the amount of air delivered a revolution; the fan is not, nor can it be made to do so, whatever its construction. How far this is beneficial will appear farther on. The fan is able to produce a pressure from the fact that air possesses a light specific gravity, and by setting in motion arms or beaters at a high speed, sufficient centrifugal force is produced to repel the particles of air outwards or towards the delivery by beating it. By rapidly increasing this centrifugal action, its density and consequent pressure may be effected up to a certain point.

In the blower, however, the quantity of air forced forward at each revolution is practically the same, whether making 100 or 200 revolutions a minute, and does not in any degree depend upon centrifugal action, or upon the specific gravity of the air to give a definite displacement; and this commends the blower, as a source of economy in promoting the combustion of the fuel in the furnace, and in the power necessary to drive it, as the difference in speed alone in the two machines varies from 100 to 5000 revolutions a minute.

In order, therefore, to maintain a pressure such as is ordinarily required for smelting iron, the fan must sometimes run at a speed dangerously near the bursting strain of the materials of which it is composed, whilst there is a limit to the pressure which can be attained by this centrifugal force, and when that limit is reached no more air will be forced forward, however the speed may be increased, thus absorbing power uselessly. This fact admitted, it follows that the effectiveness of a fan to deliver a given quantity of air, is proportionately impaired by the degrees of resistance which are brought into operation during the melting process; and this argues that there is a constant uncertainty as to the amount of air entering the cupola, whilst it is equally clear that under such conditions the same, nay more, air is required in the interior of the furnace to produce an economical yield of iron a lb. of fuel burnt. As the melting proceeds the tuyeres become foul from the accumulation of slag and cinders in the interior, to such an extent that the melting ceases, and the iron is rapidly decarbonized, loses its fluidity, and is quickly chilled, so that the castings are bad from being run short, too hard or unworkable with the tools which follow, producing much waste.

We have testimony from many ironfounders on this important point; in many instances inferior brands of iron are used with the blower blast, for precisely the same class of work as formerly required the most expensive pigs when the fan was used, and with better results.

We cannot reduce iron without fuel, but there is a necessary quantity, and the proportion of air is as definitely fixed for its complete combustion; any excess of either is simply so much extra cost put upon the cost of the castings produced.

We know also that there is a certain degree of heat necessary to melt the largest amount of iron

in a given time, with the least amount of fuel, but it is possible to consume any quantity of coke without melting a single pound of iron, if the temperature is not sufficiently elevated by a judicious admission of the necessary oxygen, to combine with the carbon of the fuel; so that a machine delivering a fixed quantity of air in a given time, is as necessary as the knowledge of how much coke is required a ton of iron put into the cupola. But as combustion can only proceed at a certain rate, it is equally important that too much air is not forced therein, otherwise the temperature of the furnace gases is lowered.

When the proper amount of air is supplied the combustion is perfect, and the highest rate of melting is attained; but then we must remember that as the carbon seizes upon the oxygen of the air and converts it into carbonic acid on its entrance at the tuyeres, so this compound is rapidly reconverted into carbonic oxide as it ascends through the charge, from the liberation of the hydrocarbonic and other gaseous elements of the fuel; and that, in order to secure the highest temperature and efficiency, we must be enabled to inject continuously a given quantity of this oxygen to prevent the formation of carbonic oxide, and this can only be done by some machine which delivers positively, under all conditions of the furnace, a fixed quantity.

We have said enough to prove the importance of fixed quantities of fuel, air, and iron in the economical production of castings; but Table V. illustrates forcibly what actually takes place in the cupola, showing the operation of the blast in actual work, using a Baker's blower, and comparing the pressure with those of a fan. Blast given with a No. 17 Baker blower, running 93 revolutions a minute, blast pipes cast iron, and perfectly air-tight.

When the blast is first put on, the pressure will be somewhat near 10 oz., slightly diminishing the first fifteen minutes, until the iron commences to melt, then, rapidly increasing in pressure until the highest limit is obtained, which is in about an hour and a quarter after the blast is put on. The fuel used was the best anthracite lump coal, and the iron was two-thirds pig and one-third sprues, small gates, fine scrap, and the like, at last of the heat.

The average amount of power, number of lb. of iron melted to each lb. of coal used, and iron melted to the lb. of coal, are given in Table V.

Table V.—Work done by 37-inch Cupola and Baker's Blower.

Reference Letter to Trials.	Time in Minutes.	Average Horse-power during Heat.	No. of lbs. Iron Melted.	Lb. of Coal used.	Iron Melted an Hour.	Iron Melted a Minute.	Lb. Iron Melted a lb. Coal used.
A	92	7·45	12,000	1,500	9,729	162	8,000
B	99	7·40	12,000	1,450	8,780	146	8,275
C	100	7·55	12,100	1,550	9,075	152	7,800
D	101	7·60	12,550	1,550	9,181	153	8,032
E	101	7·50	13,873	1,650	8,950	140	8,403
Average ..	101	7·50	12,504	1,540	9,143	152	8,102

A careful study of the experiment reveals several important facts to which we would call attention.

1st. The ever-varying conditions of the furnace as regards the pressure of blast to produce the results.

That, under ordinary circumstances, such a resistance to the passage of the air through the charge in the furnace is imposed, as to cause a considerable increase in the pressure of the blast, and that if the machine is not capable of answering such conditions, there must be a corresponding loss, both in fuel and the quality and quantity of castings turned out in a given time.

Seeing that the highest pressure required is from 20 to 24 oz. a sq. in., it is impolitic to employ a fan whose highest duty is 16 oz.; not that pressure is absolutely necessary for smelting in the cupola, but that in order to introduce the necessary amount of oxygen to the pound of fuel, the internal resistances reach such a point, as to cause a corresponding increase in the density of the air.

As a mere question of mechanical arrangement, simplicity and economy of power, there is a decided advantage in the running at a low speed with a positive displacement a revolution, and we also know exactly what air is being delivered with a blower.

See Coal Mining, Ventilation.

FOUNDING.

The art of casting metals, or founding, is of essential aid to the mechanical engineer, as he has to employ it largely in his constructions. It includes furnace practice, pattern making, moulding, casting, mixing of metals and their alloys, with other minor matters.

Reverberatory, air crucible, and cupola furnaces are those principally used in founding.

The chief object of a cupola furnace is the melting of cast iron; any reducing action being of secondary consideration, as only a single chemical operation is intended to take place in the cupola, the partial conversion of the silicon contained in the pig iron into silica. As a certain percentage of silicon is desirable in cast iron, which, of all the admixtures of pig iron, is the most liable to oxidation, when the fluid or semi-fluid iron is exposed to a jet of atmospheric air, it is necessary to select a description of pig iron containing a surplus of silicon, which is reduced to the right proportion by the oxidizing agency of the blast. No other change in the composition of pig iron, especially no reduction, is intended, and this constitutes a fundamental difference between the cupola and the blast furnace.

The blast furnace is used for the purpose of eliminating oxygen, or, as this is mainly achieved by carbonic oxide, of generating this description of gas, and of exposing the ores to its deoxidizing agency.

That portion of the blast, which as a matter of necessity is converted into carbonic acid immediately after entering the furnace, has to be reduced to carbonic oxide as quickly as possible, for the purpose of preventing the ores from melting at too early a stage. The fusion of the ores takes place after the reduction has been effected, and is confined to as small a zone of the furnace, and to as short a time, as possible.

The cupola, on the contrary, is solely adapted for melting in the best possible manner, by generating the largest possible number of caloric units, or by converting the whole of the fuel used into carbonic acid by means of the blast.

If a blast is forced into a furnace at a comparatively high pressure, the surface of the jet exposed to the fuel will be comparatively small; the combustion will be incomplete, and carbonic oxide will be the result. If the same quantity of air is introduced into the furnace within the same time, under comparatively low pressure, the air will expand in the interstices between the fuel as soon as it enters the furnace; the points of contact between the oxygen and the carbon will be multiplied, and a complete combustion, resulting in the production of carbonic acid, will be the result.

The degree of combustion, or the quantity of caloric obtained by it, depends upon the proportion of the surface exposed by the blast and the fuel to each other. This offers an explanation of the fact, that a dense fuel has proved to be advantageous in the cupola, where the generation of caloric is the principle object aimed at. Charcoal will never give as good results as coke, because the surface offered by it to the blast is far too large, and could only be made proportionate by a partial evacuation of the interior of the cupola.

A partial reduction of the carbonic acid, produced by the blast of a cupola, to carbonic oxide cannot be prevented. The additional quantity of carbon effecting this, and the necessary caloric for converting this carbon into a gaseous state, constitute a loss, which, however, is diminished by the use of a dense fuel, and by the circumstance that the pig iron, whilst melting, absorbs a considerable quantity of heat, from a portion of the carbonic acid generated by the blast, whereby the temperature of this portion is lowered, to such a degree that its reduction to carbonic oxide becomes impossible.

The first of these losses may be considerably reduced by a proper height of the cupola, from 8 to 10 ft. above the tuyeres being sufficient to reduce the temperature of the waste gases to an average of 120° F.

The quantity of heat lost by conduction cannot be lessened by an extra thickness of the lining, as was formerly believed, but may be very materially reduced by melting the pig iron down quickly. The ratio of the number of heat units produced by the generation of carbonic acid to that by carbonic oxide, is as 8 to 5 for equal quantities of atmospheric air, and as 3 to 1 for equal quantities of carbon; the quantity of pig iron melted will, as a matter of course, increase, and the loss of heat for each unit of weight of pig iron, occasioned by conduction, will decrease in the same ratio.

All modern constructions of cupolas which have been attended with more or less success, have been based upon these two conditions; the greatest distribution of the blast, for the purpose of bringing down the pressure, and enlarging the surface of contact between the blast and the fuel, and plenty of it, in order to increase the quantity of pig iron that is to be melted down within a certain time.

If these systems are carefully carried out, the results will be almost identical, the ratio of the weight of pig iron to that of coke, by which it is melted, being a maximum of 100 to 6.

The following data have been proved by practical experience;—The pressure of the blast should only be due to the obstruction offered by the coke and iron in the cupola, and never to a diminished section of the tuyeres; it ought not to be much less than 8 in. of water column, 0·28 lb. on the sq. in., and not more than double that. The aggregate sectional area of the tuyeres should not be less than $\frac{1}{8}$ of that of the shaft; it is frequently as $\frac{1}{5}$, and even more. The sectional area of the narrowest portion of a cupola shaft should be about 150 to 190 sq. in., for each ton of pig iron to be melted an hour. The quantity of blast a second, required to melt a ton of pig iron in an hour, is from 41 to 49 cub. ft. a sq. ft. of the sectional area of the shaft.

The difference of opinion formerly existing as to the thickness of the lining, has been settled by experience in favour of thin linings; generally speaking, a thickness of 7 in. is sufficient for a cupola working three to four hours a day; in case of a longer working time, the thickness should be increased to about 10 in., and for cupolas working all the day long it is taken 11 to 12 in. thick. Thick linings absorb more heat, which is wasted every time the cupola is blown out; besides, they are not cooled by the atmosphere as effectively as thin ones.

The cupola has the great advantage of melting iron cheaper than any other furnace, and of being a very convenient apparatus, as from $\frac{1}{2}$ a cwt. to 5 or 6 tons may be melted in a short time, with a comparatively small quantity of fuel, in furnaces differing only slightly in size and form.

The cupola, being only intermittently at work, does not afford the same facilities for utilizing the waste heat passing off from the top as does the blast furnace. The same reason also militates against economy of fuel, as the cupola has to be lit up very frequently, an operation which consumes a large proportion of the fuel used. Yet a well-constructed and properly managed cupola is a tolerably efficient apparatus, and does not offer a margin for any very material decrease in the consumption of fuel, which, with fair materials and management, may be taken to average $2\frac{1}{2}$ cwt. of good coke to the ton of liquid iron, although the work has been done with a much smaller consumption.

In modern practice the cupola is built of a cylindrical form, the casing being either of wrought-iron plates or of cast iron. When the casing is of cast iron it is advisible to strengthen it with wrought-iron hoops, especially in the case of a large cupola. Cast-iron casing is most durable, and can be made with projecting flanges to bolt the segments together, and upon which the wrought-

iron hoops should be shrunk whilst hot. The economy of coke is principally determined by having the cupola of the correct height proportionate to its diameter.

When the maximum diameter does not exceed 4 ft., the height may range from five to six times the diameter. With cupolas having a larger diameter than 4 ft., the height should not exceed four to five diameters, up to the feeding aperture.

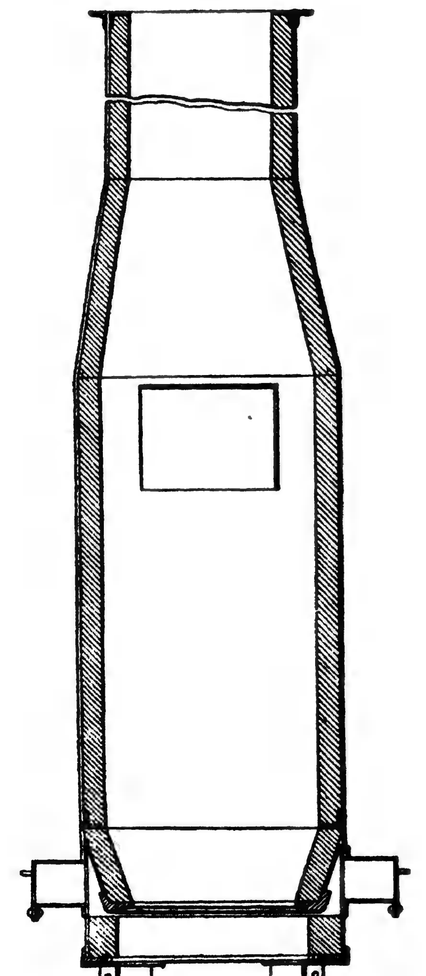
The objection to a very great height of cupola, is the increased time and labour involved in raising the materials for charging, and wherever the height is considerable, efficient mechanical arrangements are, of course, required for this purpose.

The diameter of cupola is also subject to much variation, ranging from 18 in. up to 4 ft. or even larger. A cupola 18 in. wide, with one tuyere, will make good hot metal if worked with charcoal, but to work satisfactorily with coke requires a cupola at least 2 ft. diameter with two tuyeres; and with anthracite a cupola, to produce the same result, should be 2 ft. 6 in. diameter. A well-built chimney should be connected to the cupola, although for moderate-sized works a sheet-iron chimney is generally found to answer.

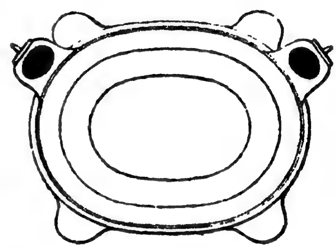
The prevailing interior horizontal section of the majority of cupolas is, at the present time, circular, however varied in other respects they may be.

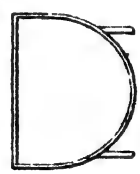
A cupola of this description has been known to melt from 10 to 20 tons of iron a day with but

1250.



1251.





1252. 1253.

120 lb. of coke to the ton of metal melted, which consisted of various mixtures of Cleveland hematite and Scotch pig. The diameter was 3 ft. 6 in.; height from tapping hole to charging floor, 14 ft. It was supplied with blast from a blower, at a pressure of ·25 lb. to the sq. in., and melted at the rate of about 5½ tons an hour.

The construction of Krigar's cupola is shown at p. 2365 of this Dictionary. It has not come much into use in England, and recent German examples are considerably modified, being circular in section, and having a chamber arranged where the breast is placed, this chamber being at a lower level, and practically acting as a collecting ladle, the metal being run from it through a taphole in the ordinary way.

The Mackenzie cupola, Figs. 1250, 1251, is largely used in the United States. It is generally elliptical in plan, Fig. 1251, and the blast, instead of being supplied through tuyeres, is admitted through an opening which extends completely round the bottom part of the cupola. The blast is led into a chamber surrounding the boshes of the cupola, and from thence it escapes through the annular opening into the furnace. The cupola is fitted with a drop bottom, seen in detail, Figs. 1252, 1253, which arrangement is almost universally adopted in the States.

American cupolas as a rule are large in diameter, which is an essential feature when anthracite, the fuel most common in America, is used. An arrangement often adopted is to have the sides parallel, but with a convex shaped belt, of the same material as the lining, arranged just above the

tuyeres, this belt effecting the same object, although imperfectly, as the boshes in such forms as those of Ireland or Voisin.

Ireland's cupola is built with boshes, and has a cavity of enlarged diameter below them, so as to give increased capacity for the liquid iron. One arrangement of it has two ranges of tuyeres, ordinary ones at the bottom, and smaller but more numerous tuyeres above the boshes.

Ireland's directions for the management of one of the cupolas were as follows;—

"The small cupola must be filled with coke about half-way into the boshing, and then put on about three handfuls of limestone. Then put on the pig metal across the centre of the furnace, with the ends of the pigs towards the tuyeres, piling up the sides with scrap, and cover the whole with coke. If the weight of metal be 20 cwt. put on 10 cwt. at a charge, proportioned, 7 cwt. of pig iron and 3 cwt. of scrap, and cover well with four riddles of coke. If the weight of iron be between 20 cwt. and 26 cwt., divide it into two equal charges, and put between each of the charges four riddles of coke. Put three handfuls of limestone between every charge. If the weight of metal be 30 cwt., or up to 40 cwt., divide it into three charges, and put on coke as above stated."

The superiority of Ireland and Voisin's cupolas over the old construction, consists in the shape of the interior, the height, and the perfect system of charging. Owing to the shape of the interior, the charges are kept up by the boshes alone, and as they gradually descend the incline they are melted; consequently the only portions of the lining of the cupola that are subject to wear, are the boshes and the sides of the crucible.

Woodward's steam-jet cupola is worked by means of an induced current, caused by a steam jet blowing up the chimney of the cupola, instead of by blast forced in below. It is asserted by those interested in this cupola, that it effects a great saving in fuel over the ordinary fan-blast cupolas, and it seems tolerably certain that it is at least as economical as the best ordinary furnaces where fans are employed, with the additional merit of great simplicity.

The steam required to create the draught, is only equal in quantity to what would be consumed by an engine, for driving a fan of sufficient power to work an ordinary cupola of the same size.

Heaton's cupola is constructed by building a tall stack on the basis of a cupola, and providing the latter with two rows of large tuyeres; the heat and draught are maintained simply by the ascensive power of the hot air passing up from the cupola and stack or chimney.

Voisin's cupola, Figs. 1254 to 1256, is a good form. It is constructed of boiler plate, in thick double riveting, in this instance, and lined with firebrick made to the shape of the interior. The bottom is arranged to drop after the American plan, sufficient space being allowed beneath to accommodate a truck or trolly, for conveying away the broken bottom and contents remaining when the furnace is drawn. The blast is supplied from a belt completely surrounding the cylinder of the boshes, and from this belt two sets of tuyeres, four in each set, deliver the necessary supply of air. It will be seen, Figs. 1255 and 1256, that the lower set are arranged opposite and at right angles to the main, while the upper set are diagonal to it. The inventor claims through this arrangement of the tuyeres, that the gases being burnt in the interior of the cupola, create a second zone of fusion with those gases alone. In other words, the second set of tuyeres obviate to some extent the evil effect of the formation of carbonic oxide. Voisin's cupola has certainly been very successful, and the more so, we are inclined to think, owing to the careful proportioning of every part given to it by the inventor.

A portable cupola with its fan is shown in elevation, Fig. 1256*, it is formed of a cylinder A A, of sheet iron $\frac{1}{16}$ of an in. thick, 2 ft. 3 in. in diameter, and 4 ft. 6 in. high, lined with firebricks and clay, in the usual manner, 4 in. thick.

The cupola weighs about 6 cwt., and is easily lifted by the workmen on to a trolly and taken to the place required, when it is lifted off and placed on a temporary staging.

The cupola has a belt or air chamber at C C, into which passes the air from the fan D, and it has four tuyeres of 2 in. orifice to admit the air to the fire. The yield of metal from so small a cupola was great; as much as $3\frac{1}{2}$ tons have been run down in seven hours by two men turning the handles of the fan, and nearly $4\frac{1}{2}$ tons by the use of the engine in the same time.

Numerous other forms of portable cupolas are known, but none of them appear to be as efficient and simple as that illustrated, which was employed some years since melting metal for a special purpose on one of the large railway lines.

In the disposition of a range of cupolas, attention should be particularly directed to placing them conveniently for access with the raw materials, all of which, it must be remembered, have to pass along the charging platform to the furnace mouth, and are much more bulky and weighty than the output of castings. It is advisable to keep the cupolas, the tapping floor, and the charging platforms in a separate building from the rest of the foundry, but communicating with it, and to have it covered with a light corrugated iron roof, but provided with means of obtaining ample ventilation.

The charging platform must be strong enough to bear the passage of the heavy loads of materials passing over it, and of sufficient area to allow of the separate stacking of the coke, limestone, pig and scrap iron employed in each cupola; also for the firebrick and fireclay required in repairs and lining.

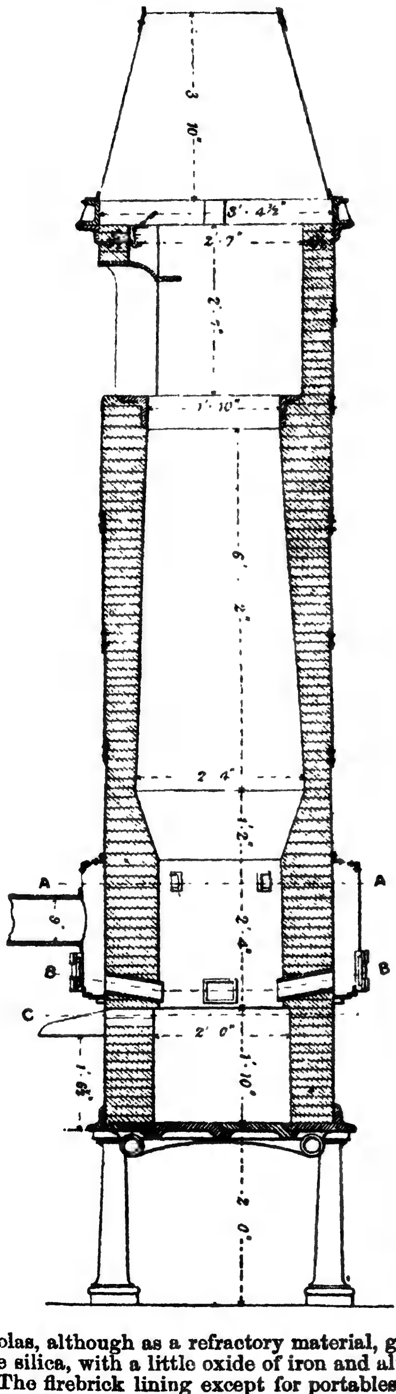
There are various methods employed for raising the materials on to the charging platform, the most costly and inconvenient of all being manual labour, except in cases of very small foundries.

A travelling steam-crane, which can be moved to serve any one of the range of cupolas, or a hydraulic lift, such as that on p. 2250 of this Dictionary, which will hoist a truck load of coke or iron from the ground level to the platform, are the arrangements employed in the best works; all materials reaching the charging platform pass over a weighbridge, and the furnaceman in charge has to keep an account of these deliveries.

Immediately over every cupola should be a hood, which may be supported by a ring of cast iron on pillars resting on the top plate of the cupola, the hood itself being of sheet iron, or built of good red brick set in fireclay, with a considerable taper, and having hoop-iron bands at intervals of from 2 to 3 ft. the whole way up.

The common cupola, for the height of about one diameter, should have its sides built parallel, after which they may gently taper inwards to the height where the top plate receives the pillars for supporting the hood, the whole being lined with the best firebrick, and all the spaces between the pillars and the hood ring are also to be filled in with firebrick, except the opening, which is to be left between two of the pillars for the feeding aperture.

1254.



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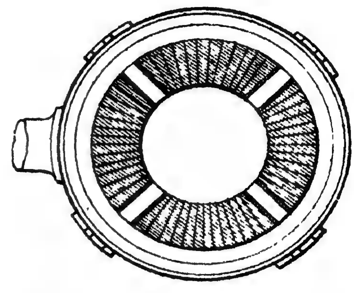
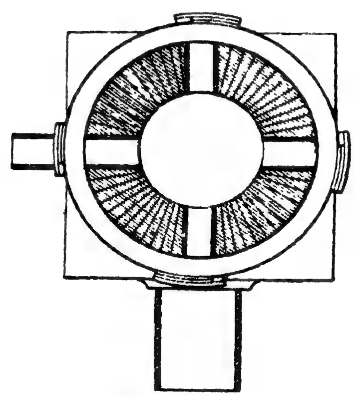


The cupola may also be lined with a mixture of fireclay and river sand, firmly rammed in, and slowly dried; or with road mud, when obtained from a road macadamized with flint or hard sandstone; but the latter must not be used if it contains any iron or lime, and is not to be recommended as very reliable. The lining should be at least 7 in. thick, and may be thicker if made of firebrick. The bricks must be set in fireclay mortar, consisting of refractory sand, and as much fireclay as is needed to hold the sand together.

1256.



For small cupolas a lining of well-rammed ganister may be used, or washed scrapings from off flint roads, if in a clay district.

The material was at one time commonly applied by ramming it down between the inside of the cupola and the outside of a wooden block of the same shape as the interior, but so much smaller as to leave the desired space for the lining. The wooden block must be so made as to be easily taken to pieces to be removed, on the principle of a bootmaker's last. This plan is still occasionally practised, especially in France. Great care is required in drying this lining, as it is difficult to prevent unequal drying, when parts of the lining will probably become detached the first time it is put in blast.

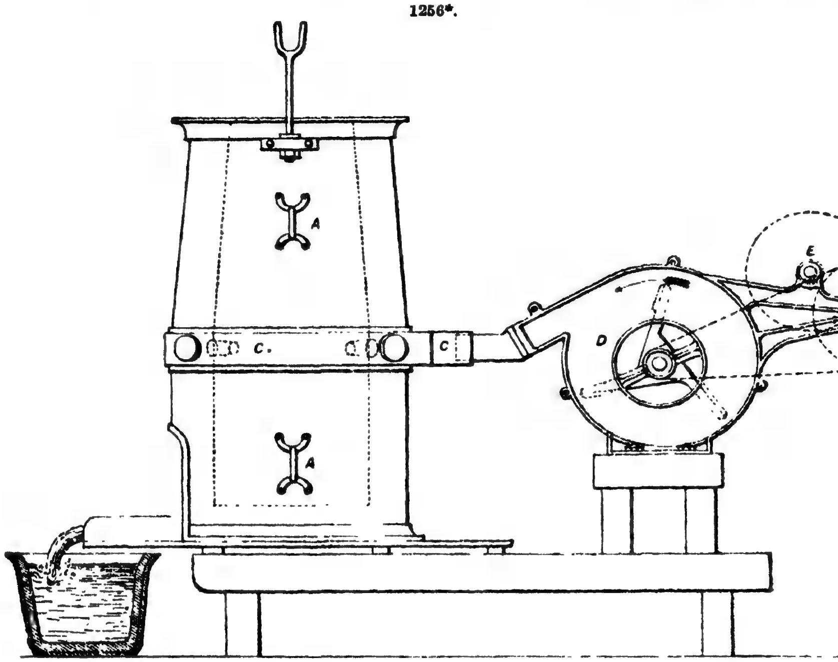
It is therefore decidedly preferable to use special firebricks, or lumps, for the lining, especially of large cupolas, although as a refractory material, ganister is scarcely to be surpassed, consisting of nearly pure silica, with a little oxide of iron and alumina.

The firebrick lining except for portables, should have all the bricks laid as headers with fireclay joints not exceeding about one quarter of an inch in thickness.

The fireclay used for this purpose, and also for backing up the brickwork to the casing of the cupola, should be the same clay as that from which the firebricks have themselves been made, so that when at a high temperature, there shall be no tendency to any chemical reaction, such as might be caused by only a slight variation in the constituents of the clay. Many furnace builders merely dip the bricks in a thick cream, composed of the same materials from which the bricks were made.

The damp, loamy sand used for the bottoms of cupolas should not contain much alumina, and

1256*.



should be rammed well down, especially where it touches the walls. It should be about 6 in. thick, at the outer edge, slightly hollowed towards the centre, and with a good fall towards the tap hole.

When the cupola has a movable iron bottom, care must be taken not to put so little sand on it as to risk burning the trap away, whilst on the other hand, if the bottom is too thick, it will be more difficult to break down when it is wished to empty the cupola, especially if the sand contains a large percentage of clay, tending to make it bake hard and solid.

The tuyeres for large cupolas may be protected from the heat to which they are exposed, in the same manner as blast-furnace tuyeres, but the destructive action to which they are liable is less than that which blast-furnace tuyeres have to bear, where they carry in highly heated blast into the furnace.

The usual method of protecting a tuyere is by keeping up a circulation of cold water round it, which is effected in a variety of ways, great care being necessary to prevent any leakage into the furnace, a source of much danger to the men.

Until recently all the tuyeres in use since the introduction of hot blast first necessitated a water tuyere, may be classed under two heads, namely, the coiled tuyere and the water-jacketed tuyere.

The coiled tuyere is generally made of a coil of wrought-iron tube imbedded in the sides of a hollow case of cast iron. Sometimes the coils are wound close at the nose of the tuyere, in order more effectually to prevent the cast iron from burning; and sometimes the tuyere itself is formed entirely of a coil of tube, closely wound from end to end.

The water-jacketed tuyere is generally made of wrought iron, and consists of two conical tubes of different diameter, connected at each end by rings of wrought iron welded in, so forming a space between the two concentric walls of the tuyere, which is filled with water supplied under pressure, and generally brought in through a feed-pipe at or near the bottom of the tuyere, and allowed to escape through a second pipe in the upper side.

Phosphor-bronze tuyeres are generally fixed in a cast-iron casing or box, beyond which they project into the furnace for the greater part of their length, and they are so arranged that they can be turned round in the cast-iron plate or box, in order to expose a different side of the tuyere to the action of the materials in the furnace. Greater durability is claimed for phosphor-bronze than for gun-metal or copper, but each metal possesses the same advantage of preventing adherence of slag, scoria, or iron to the nozzle of the tuyere, which is the only object to be gained by the use of copper or its alloys in preference to iron. Additional precautions as to water supply have to be taken where such metal is used; as, owing to the low temperature at which it melts, a copper

tuyere may be more rapidly destroyed than an iron tuyere where any overheating is possible, but under favourable conditions both gun-metal, copper, and phosphor-bronze tuyeres have been found very durable, and the advantage gained by keeping the blast nozzle always clean and fully open, is an important one.

The open spray tuyere invented by F. H. Lloyd, consists of two concentric conical tubes, closed at the nozzle but open at the rear end. The supply is connected in the usual manner with a flexible hose, and various systems of spray pipes are used to suit various shapes of tuyeres and various conditions of water supply.

The number and position of the tuyere holes very much depend upon the size of the cupola, the quality of coke, and the nature of the pig to be employed.

For some small cupolas only one tuyere is used, which is placed at the back of the cupola, about 15 in. above the bottom. According as the diameter of the cupola is increased, so must the number of tuyeres be increased around it, in the same horizontal plane, so as to generate a uniform heat at all points in the furnace. If the cupola is of a comparatively small diameter, several tiers of tuyere holes should be arranged, one above the other, 8 or 10 in. apart, so that if it is required to melt a large quantity of iron at once, the tuyeres can be raised from the lowest range of tuyere holes to the range next above it, the first range being plugged with fireclay; when the iron is melted to the level of the second range, it is also stopped up, and the next higher put in operation. But the process is much simplified by having a cupola of large diameter, capable of holding a considerable quantity of liquid iron, with but a small rise in height inside. There is then no necessity for more than two or three tiers of tuyere holes. Of course, these observations do not apply to cupolas furnished with a belt.

Assuming a cupola to be capable of yielding 2 tons of liquid iron an hour, when in good blast, with one shift of the tuyeres, and that a 10-ton casting is required, the process would be as follows; The first 2 tons would be tapped and run into the ladle, when the tapping hole would be closed, and blast again put on. The metal in the ladle would be covered with about an inch of charcoal dust; at the end of the hour the second tapping would take place, and melting again be resumed, until the five successive tappings had been taken from the cupola, and the ladle contained the required quantity of 10 tons of iron, of a sufficiently high temperature and liquidity for large castings. For although the first metal that is tapped is somewhat cooled by contact with the cold ladle, and has to remain in it for upwards of four hours, yet each successive tapping is of a higher temperature than the preceding one, as the cupola gets hotter the longer it is at work, and the metal in the ladle is therefore maintained at a sufficiently high temperature.

If still larger castings are required, the metal can be accumulated in this way in ladles from two or more large cupolas, without the inconveniences of the shifting tuyeres, and the dangers arising from the pressure of great heads of metal necessarily incurred with cupolas of small diameter. There is, however, a limit of time in this intermittent process. In the first place, the metal must not be kept too long in the ladle before pouring; and in the next place, slag will accumulate in the cupola, and the yield of liquid iron an hour will be considerably decreased.

The air main from the fan to the cupola is provided with one or two upright cast-iron pipes, which may either lead into another pipe surrounding the cupola, or be connected directly to the tuyeres.

In arranging the air main from the fan to the cupolas, by-pass valves should be so arranged that the blast can be shut off from any one cupola at any moment, without interfering with the supply of blast going to the others. In some forms of those furnaces provided with a belt, means are provided for separating the blast of the upper or lower row of tuyeres, or again from any particular pair of tuyeres, at will.

One of the most important modern modifications in the construction of the cupola has been the introduction of the falling hinged trap-door, Fig. 1254, to allow of the whole contents to be dropped into a pit beneath the cupola after tapping; by this arrangement the cupola is much more easily and quickly emptied than by the old and fatiguing process of raking out. When this can be adopted, that is, when there is the power to have a clear gangway left beneath the range of cupolas, it is necessary to pay great attention to the proper arrangement and strength of the supports.

A brick tunnel for the blast pipes should be built behind the cupolas, the back and fronts carried on strong brick piers, with a vaulted brick passage passing directly under the cupolas, leaving the central portion of the bottom of each cupola quite free. Light iron trucks running on rails laid in this passage will be brought under any cupola that is to be emptied, will receive its load of coke and slag, and will be run away to the pit, where its contents will be emptied and quenched, preferably by a hose and jet, so as to avoid unnecessarily saturating the coke, as is done when it is bodily cast into water troughs to be cooled, and when the coke is again used, the whole of that water has to be evaporated.

The mode of forming the trap-door is to build the brick lining of the cupola so that it rests upon a strong flanged iron ring, which is supported by cast-iron columns resting on the brick piers. The central circular aperture, as large as the interior of the cupola left by this ring, is closed by a wrought-iron trap-door hinged to the back of the cupola, and secured in its place by bolts, which can be easily drawn by a sharp blow, so as to let the trap fall vertically, when the whole of the contents of the cupola will be received in the trucks beneath.

The trap, being left open, allows a current of cold air to pass up through the cupola and chimney, so that in the course of about twelve hours the lining has cooled down sufficiently to allow the men to repair it, and put in a fresh bottom of loamy sand.

In places where this system cannot be adopted, and the raking out of the cupola from the front, on the old plan, is to be used, the breast opening should be left about 2 ft. square, to be closed by a falling apron of wrought iron, having a small opening left at its lower edge for the tapping hole, 4 or 5 in. wide by 6 or 7 in. high.

When the cupola is to be charged, the apron is left full open; firewood and coke are charged into the cupola and ignited, and when the coke is well alight, a quantity of loamy sand is shovelled into the breast opening until it is quite full, and is tightly rammed in; the apron is then brought down forcibly through the superfluous sand, or the apron may be closed before the fire is lit, and the furnaceman, when putting in the sand bottom, must also fill up the breast opening with the same material, solidly to the iron apron, and to the full thickness of the brick lining of the cupola.

In either case care must be taken to preserve the tapping hole open, which must be on the level of the shoot outside. The tapping hole is, of course, placed so as to come within the orifice left on the breast opening.

When the metal commences to flow, the tap hole is closed in the usual way. When it is desired to take out cinder and slag from the cupola, after tapping, the apron is removed, and part of the sand breast broken away, and the furnace easily cleared within.

In charging coke into the cupola, a wide steel fork, with about eight round tines or prongs, will be found more convenient and economical than the common shovel generally used, as the coke will be less broken, whilst the breeze and dirt will not be thrown into the cupola as with the shovel. In cases where the coke is very friable, or has had to bear much carriage, the percentage of breeze becomes a material element in the cost of fuel; if thrown into the cupola much of it is immediately blown away, whilst any dirt put in with it of course represents so much the more slag to be dealt with. The breeze, if kept clean, can be ground into coke-dust to be used by the moulders.

Supposing the cupola to be cool, but in good working order as to lining and tuyeres, the falling iron door at the bottom, if the cupola is provided with one, must be closed, and securely fastened in its place, and well covered with sand; moulding sand is used when only a small quantity of iron is to be smelted; if a large quantity of melted metal is required, a more refractory sand is desirable. A wood fire is then lit in the cupola, upon which coke, coal, or charcoal is placed, the tap hole being left open to supply air to support the combustion, the tuyeres being also left open. The cupola is then filled with fuel, which is kept in brisk combustion. It requires several hours to heat the furnace for blast, which is not laid on until the flame appears on the top of the fuel. When the furnace is thoroughly heated, the nozzles are put in, and the fan, or blower, is put to work. Before putting on the blast, however, the large tap hole must be closed with moulding sand, or good fire proof clay and sand mixed, leaving a small hole at the bottom, which serves as the tap hole for the iron. This should be about 2 in. diameter, and is formed by placing a tapered iron bar in the place where the hole is to be, ramming the sand tightly around it, and removing it as soon as the hole is properly and securely moulded. When the blast is put on it will drive a flame through the tap hole, as well as out of the top of the cupola. The tap hole is left open to dry the fresh loam and sand, and also so that its sides may be glazed or vitrified by the heat, so as to resist the friction of the tapping bar; the heat also serves to glaze the lining of the cupola in those parts which have been mended with fireclay since the last smelting.

When the cupola is intended to hold a large quantity of iron, the large tapping hole should be covered with an iron plate, securely fastened to the iron casing, leaving only the small tap hole open.

Charging with iron is commenced as soon as the lower parts of the furnace show a white heat, which is best known by the colour of the flame issuing from the tap hole, it being at first a light blue, but afterwards becoming of a whitish colour. About ten minutes after charging the iron, the melted metal appears at the tap hole, which must then be closed by a stopper made of loam, which has been worked by hand to a proper consistence; a round ball of this is placed on a disc of iron at the end of a wooden rod, and is forced into the tap hole; this is also done when it is wished to stop a tapping out with the bott or bod stick, as it is called, but is then a more difficult operation, as the molten iron frequently squirts out past the bott stick whilst the men are trying to apply the plug.

Pig iron is broken into pieces of from 10 in. to 15 in. in length before it is charged into the cupola. This is a very laborious operation, especially in the case of tough pig iron. The first breaking is generally accomplished by throwing the pig down heavily upon a piece of old iron fixed in the ground, after which it is broken up still smaller with a sledge-hammer. This work is now very often performed by an adaptation of Blake's, or some other, stone crusher.

From 10 lb. to 12 lb. of fuel are charged for every 100 lb. of iron; but this quantity varies, depending much upon the nature of the fuel, of the iron to be melted, and upon the size and construction of the cupola. Along with the coke and iron, limestone must be put in, broken up into pieces about 2 in. cube, or oyster-shells, in quantities varying from 2 to 5 per cent., according to the nature of the fuel and iron. Too much limestone, as well as too little, causes the iron to become white, to lose some of its carbon, and, in many cases, its strength and softness are greatly impaired.

The limestone, when used, is commonly introduced into the cupola after the first charge of metal. It is intended to act as a flux, and combine with any earthy matters that may be present in the metal and coke. With these it forms a glassy compound, and, by this means, the iron is freed from such impurities as it falls to the bottom. The slag, as it is termed, floats on the surface of the iron collected at the bottom, and frequently makes its appearance at the tuyeres in a solid state.

The cupola should be kept full whilst in blast, or at least so long as iron is melted, by alternate charges of iron, fuel, and limestone. Fuel is generally put on first, then iron, and, lastly, the limestone, and the charging continued without intermission, until all the iron required at that time is melted, when the charges are stopped. The blast is, however, kept on until all the iron has been tapped. As a matter of experience it has been found that the interior form of a furnace greatly affects the condition of the metal, and thus influences its applicability to certain uses; thus,

cupolas which are larger in diameter at the bottom than at the top, work hotter than those with parallel sides, and also last longer, as the melted iron, which is apt to cut the firebrick, then sinks more through the materials in the body of the cupola than it does in cupolas with parallel sides. The amount of taper to be given to the lining depends upon the size of the cupola; a large one will bear more taper than a narrow one.

If it is intended to melt different qualities of iron in the same heat, a thick layer of fuel should be placed between the various brands, so as to allow of the extraction of all the iron which was first charged, before the second appears at the bottom. In such cases it is preferable to first melt the grey iron, or that iron which is to make soft castings, and white or hard iron afterwards.

When as much iron is melted as is required, the clay plug of the tap hole is pierced by a sharp steel-pointed bar, or iron rod driven by a hammer, and the metal run into pots, or it is run directly into the mould by means of gutters moulded in the sand of the floor. Between each successive tapping of the iron the tap hole is closed, and more iron is allowed to accumulate in the bottom of the cupola.

Where more iron than the furnace will hold is required for one casting, a portion of it is poured into a large ladle, which is kept until another charge is ready, and this process, as before remarked, may be so managed as to obtain good-sized castings from a small cupola.

Less coke is consumed when the fusion is pushed more rapidly to collect a greater quantity of metal for heavy casting, as the iron required besides is not so hot as for smaller castings. About one-half more coke, on the contrary, is consumed in melting metal for hollow ware and ornamental work, as these thin, straggling castings require metal at a much higher degree of heat than the larger; and were such metal suffered to remain long in the bottom of the furnace, it would run a risk of getting too cold to afford sharp impressions of the moulds.

The greatest source of waste, however, occurs when iron is taken from the same furnace at one time for light, thin goods, and for heavy work. For as iron becomes less fluid the lower its temperature falls, it may be at first at such a temperature as will be suitable for the former kind of goods, while iron at a much lower one would be suitable for heavier casts. We may observe that when iron is drawn too hot for such a purpose as the latter, it must be allowed to cool before being poured, and the cooling is quickened by the introduction of scraps into the melted mass.

Of course in large foundries economy in coke is important, especially as the less fuel can be used the quicker the metal comes down. It must be noticed, however, that if the percentage of the fuel is too much reduced, the furnace will scaffold.

The quantity of coke consumed depends not only upon the quality of the coke itself, but also of the iron to be melted. Thus No. 1 hematite or cold-blast iron requires much more coke than Scotch or Cleveland. Anthracite coke, which is harder and denser than any other coke, requires a stronger pressure of blast for its effective combustion, and in such cases a blower is to be preferred to a fan, as giving a stronger and more effective blast. For example, a cupola has been known to melt 1 ton of iron with 126 lb. anthracite coke; the iron consisting of No. 1 Scotch, No. 1 hematite, and old cast scrap in equal proportions, the blast given by a 24-in. diameter Shiele's fan running at 1700 revolutions a minute.

It is absolutely necessary that the furnace should be kept in good repair, so as to preserve its shape, and the charges should also be made level and uniform in thickness as well as being carefully weighed. Every care in this respect must be insisted upon, as it is absurd to expect anything but wasteful results unless each charge bears its proper relation to the preceding, which can only be the case by constantly using the weighing machine.

In country works there are times when a small quantity of metal only is required to be melted, much below the usual burden of the cupola, and if for this small cast of metal it is necessary to work through with a full charge for the cupola, much fuel is unnecessarily burnt, and much time lost. One remedy for this evil, as practised in France, consists in building a cupola rather large in diameter, and lining it inside with damp, loamy sand, rammed hard into place round a number of wooden cores, which are afterwards removed. This arrangement gives the power of varying the internal capacity and shape of the cupola to a large extent, at a comparatively small cost, and with no very great delay.

The great advantage of the reverberatory or air furnace is, that it may be easily applied to a variety of different uses, with slight modifications in construction. The reverberatory and the crucible make the strongest, closest, and safest castings, whereas castings from a cupola are the weakest, except those which are obtained direct from the blast furnace.

Although the cupola has of late years almost entirely superseded reverberatory furnaces, there are several points in favour of the latter, which must not be lost sight of. The cupola is undoubtedly the cheaper and more generally convenient form of furnace, but where it is wished to turn out specially good work, and to obtain a perfectly fluid and uniform metal, the reverberatory furnace is preferable. The deoxidating flame of the reverberatory is supposed to improve the pig iron, by adding somewhat to the amount of combined carbon it contains, whereas the cupola, as usually worked, with an excess of air, is an oxidizing furnace.

In two other respects the reverberatory presents advantages over the cupola; by it it is possible to melt a given quality of cast iron more absolutely free from change in its constituents, molecular or chemical; and if the pig iron contains a large proportion of sulphur, it can be freed from a great deal of this by prolonging the time the metal is exposed, after fusion, in the reverberatory, to a slightly oxidizing flame. This latter action is however seldom of any practical utility, for pig iron that contains much sulphur makes very indifferent castings, and the desulphuration is so imperfect and unreliable, that it is usually far cheaper and more certain in working to obtain a good pig iron at the outset.

The following are generally circumstances under which it may be considered advisable to use the reverberatory furnace in preference to the cupola:—

When there are no means for obtaining sufficient blast for a cupola; when it is necessary to melt

down such large masses of metal as cannot be managed in the cupola; when it is required to bring a given pig iron, by deoxidation, to its highest point of tensile resistance, as for gun founding; and when it is necessary to erect a foundry under circumstances where a cupola with blast could not be built or worked; as, for example, in a lonely colony, a besieged town, or such other exceptional conditions.

Under most other circumstances the cupola is to be preferred, as the reverberatory is neither economical in metal nor fuel, except where the operations are constantly going on from day to day on a very large scale, and where good bituminous coal fuel is cheap.

The making of patterns is a trade in itself, and into the bench details of this trade it is not our purpose to enter.

Wood is almost universally employed as a material for patterns, pine or deal and mahogany being the kinds chiefly used. Of these pine is the most useful, in consequence of its uniformity of substance, freedom from knots, clean and easy working, and abundance. Yellow or white pine is particularly good for long and nearly flat work; it does not warp much, is not likely to split, and is light to handle. It has a fine grain, and is left smooth after the tool. It should not be roughly used, however; being soft, it is easily injured by a blow or a fall, and will be injured if placed in situations where it is likely to be subjected to such contingencies.

There are several woods which, although adapted for patterns, are still, from their tendency to split, only to be used with caution, notably teak and greenheart. Patterns made of sycamore, maple, box, and elm, generally require to be varnished or painted before being placed in sand; otherwise, however dry and smooth they may be, they may not draw cleanly from the mould.

No large foundry should be without sufficient stock of seasoned wood for patterns, nor without a properly constructed drying room for desiccating such timber. In a foundry nothing is more wasteful than the employment of half-seasoned wood, when the patterns are to be of any permanent value.

Timber is seasoned by being exposed freely to the air in a dry place, protected if possible from the sunshine and high winds. The timber is stacked so as to allow of the free circulation of air amongst it, and should be slightly raised from the ground on stone or iron bearers. If the timber is allowed to remain in water for a fortnight, the subsequent seasoning and drying is more rapid.

Time is the best seasoner of timber; but space and other economical considerations usually cause founders to abridge the time by artificial seasoning. This is often done by piling the sawn planks into racks, provided over the boilers of the engine which drives the machinery of engineering works. In large works it is much safer to have a proper oven or desiccating kiln especially made for the timber, and heat by the waste heat from some boiler or fire. When the wood is quite dry, it is best stacked in racks horizontally in the open air, but under cover from rain.

Large patterns when quite done with should be taken to pieces, and the more useful portions of timber they contain cleaned and stacked for use again. Those patterns which are to be preserved for future use should be stored in an orderly manner, exposed to the open air, but roofed over to keep them dry.

Wheel patterns occupy a great deal of room, for they must be stacked upon the flat over each other in piles, only bearing upon each other at the eyes of the wheels. They should be placed on the ground floor, which should be boarded; and in a large millwright establishment, where spur and bevel wheel patterns of 10 or 15 ft. diameter are not uncommon, a light overhead traveller would with advantage be so arranged as to pick out any pattern from any part of the room.

The upper floor answers well for all other classes of patterns. The iron and the brass or gun-metal work patterns are usually classified distinctly. But in marine engine and locomotive work, it will always be best to place the whole of the patterns for the parts of each engine together, whether they be for iron or for brass. Drawings to full size on boards, templates, gauges, and the like for such work, are best also deposited adjacent to and in order with the patterns.

Some woods rapidly imbibe the moisture from sand and adhere so firmly to the face of the mould, that they cannot be withdrawn cleanly and smoothly from it. As a precaution against these defects in the wood, and also as a preservative for the patterns, they are usually coated with varnish, or oil paint, and their surfaces made smooth and glossy. There is nothing better for this purpose than a moderately hard-drying oil paint, black-leaded over when dry. When only one or two castings are required from a pattern, especially if it should be of an ornamental and delicate character, a coating of black-lead and beer may be applied directly to the naked wood.

Pattern makers mix with their glue some good thin-drying linseed oil, in the proportion of about one of oil to four of water. The oil is added to the glue and well stirred in whilst hot. This glue is scarcely affected by moisture, and makes a strong, sound joint, although it does not set hard and glossy, like ordinary glue.

Some patterns, made of rather hard wood, such as dry mahogany, will deliver very well if coated with copal varnish. Weak shellac varnish is also a good protection.

In patterns for machinery, the parts to be got up bright should be painted of a different colour to the remainder of the pattern, then extra care in moulding may be exercised to prevent specks or other defects at these points. It is also a good plan to colour core prints differently to other portions of patterns.

When a pattern is nearly all composed of one material, it is by no means difficult to estimate the weight of the casting for which it is intended. A reference to the table of specific gravities, and a short rule-of-three sum, suffice to give the approximate weight of the casting in any desired metal, if the weight of the pattern is known. If of a simple form, its cubical contents, multiplied by the weight of a cubic inch, or cubic foot of the metal, will give the weight of metal required for the casting; and this is generally the more reliable plan, as it is quite unaffected by differences in the specific gravities of the materials used in the pattern. It is always necessary to make a good allowance for the excess of metal in the rising heads, gaits or gats, and the like.

When a pattern is made up of several different materials, and is of a form not easily to be

measured for its cubical contents, the usual plan is to weigh each of its component parts before they are finally adjusted in position, and the weight of the hard wood, iron bolts and straps, being noted down, the weight of metal required can be arrived at.

TABLE I.—APPROXIMATE WEIGHTS OF CASTINGS.

A Pattern Weighing 1 lb.	Will weigh when Cast in				
	Cast Iron.	Zinc.	Copper.	Yellow Brass.	Gun Metal.
	lb.	lb.	lb.	lb.	lb.
Mahogany	8	8	10	9·8	10
White Pine	14	14·5	18	17·5	17·8
Yellow Pine	13	12·6	16	15·5	16
Cedar	11·5	11·4	14·5	14	14·5
Maple	10	9·8	12·5	12	12·4

Papier-mâché, or plaster of Paris, should always be black-leaded, over thin hard oil paint. Cast-iron patterns should be rusted by any solution which increases the tendency of the metal to oxidize. Sal-ammoniac, dilute hydrochloric acid, or common salt in water, answers the purpose. The rust must be completely got off by the scratch brush of wire, before the black-lead is applied.

All metallic patterns are much improved in their delivery by being finely black-leaded. Prior to the application of the plumbago, the surface of brass or gun-metal patterns should be roughened, by leaving them wetted with a solution of sal-ammoniac. Zinc, solder, or type metal, or other such soft alloys, will take the black-lead at once, if the surface be free from grease or dirt.

To preserve iron patterns from rusting, and to make them deliver more easily, they should be allowed to get slightly rusty; next, they should be warmed sufficiently to melt beeswax, which is then rubbed all over them, and nearly removed; they are then to be polished with a hard brush when cold.

Cast iron, brass, zinc, plumber's solder, gun-metal and type-metal are frequently used, whilst cements, plaster of Paris, wax, terra-cotta, papier-mâché, and glass, are occasionally employed in pattern making.

Many common works, such as plates, gratings, and parts of ordinary fire-stoves are made to written dimensions, without a pattern, as a few slips of wood to represent the margin of the casting, are arranged for the time upon a flat body of sand, which is modelled up almost entirely by hand.

The pattern is a model of which the casting is to be the copy, but an intermediate stage is necessary, namely, the mould, which represents in hollows the projections which must appear on the finished casting. Each of these articles, namely the pattern, the mould, and the casting, is generally made in different materials, each of which is subject to certain alterations in size and shape, dependent upon the degree of heat to which it may be exposed, or upon changes in dryness or moisture. Thus, from the original design or drawing a pattern is made, most frequently in wood, which is then transferred to the mould; this varies in materials according to the nature of the work into which finally the molten metal is poured.

In view of these circumstances, and certain known properties of materials at different temperatures, allowances have to be made for shrinkage, from which it follows that patterns have to be made differing materially from the size and shape of the casting which is to be produced. There are several elements of complication; thus, as there must be a slight clearance allowed for removing the pattern from the mould in which it is enveloped, the hollow of the mould has to be slightly larger than the pattern. The casting itself contracts in cooling to an extent which is pretty well, but by no means accurately, ascertained, and for which a regular allowance is made. Thus, in large, heavy iron castings, $\frac{1}{10}$ in. is allowed to every foot of length in the pattern, which is found in practice sufficient to allow for the contraction of the metal on cooling, combined as it is with the slight increase in the size of the mould over the pattern. In small castings, $\frac{1}{8}$ in. to 1 ft., or about 1 per cent. is sufficient. The contraction in malleable cast iron is fully $\frac{3}{16}$ in. to the foot.

The following remarks upon this point are taken, with the accompanying table, from Thomas Box's 'Treatise on Heat';—

"The contraction which metals experience in cooling down from their melting points to ordinary temperatures is very considerable, amounting to about 1 in. with a straight bar of cast iron 8 ft. long, or with a copper bar 5 ft. long. Allowance has therefore to be made for contraction in fixing the sizes of the pattern."

Table II. gives the results of practical observations on this subject, and is very simple in application. Thus, a cast-iron girder, 20 ft. long, must have a pattern 1246 × 20 = 2·492 in. longer than itself, but a pattern 20 ft. long would give a casting ·1236 × 20 = 2·472 in. shorter than itself.

For practical purposes $\frac{1}{8}$ in. to 1 ft. for cast iron, $\frac{1}{8}$ in. for gun-metal, $\frac{1}{6}$ in. for copper, and $\frac{1}{4}$ for zinc may be taken as sufficient approximations.

The contraction of wheels is anomalous, as is shown by Table III. The irregularities in the apparent contraction arise in part from the practice of rapping the pattern in the sand, to make it an easy fit and enable it to be drawn out with facility. This is most influential in its results with small, heavy wheels of great width of face. In some cases, and in rough hands, the casting of a small and heavy pinion may be quite the full size of the pattern. The allowance to be made is therefore not uniform, but must be fixed with judgment. In large wheels, where the effect of rapping is comparatively small, $\frac{1}{16}$ in. to 1 ft. may be taken safely. A wheel is not so free to contract as a straight bar, and in any case its contraction will be less.

TABLE II.—CONTRACTION OF METALS IN CASTING (BOX.)

	Length of Pattern.	Contraction: Total in Inches.	Contraction: A Foot: Of Pattern.	Contraction: A Foot: Of Casting.	
	ft. in.				
Cast-iron girder ..	21 $8\frac{3}{4}$	$2\frac{11}{16}$	·1236	·1246	..
" " ..	16 9	2·05	·1225	·1236	..
Gun-metal bar ..	5 $4\frac{5}{8}$	1·0	·18568	·1886	Maximum.
" " ..	5 $7\frac{15}{16}$	·936	·1653	·1676	..
" " ..	5 $7\frac{15}{16}$	·97	·1713	·1737	..
" " ..	6 $0\frac{1}{4}$	1·0	·1616	·1684	..
" " ..	5 $6\frac{1}{16}$	·92	·1671	·1695	..
" " ..	5 $6\frac{1}{16}$	·90	·1635	·1657	..
" " ..	5 $6\frac{1}{16}$	·88	·1598	·1620	..
" " ..	5 $6\frac{1}{16}$	·84	·1526	·1545	Minimum.
" " ..	..	..	·1607	·1632	Mean of 8.
Copper and tin;—copper, 1·3; tin, 10..	5 $6\frac{3}{16}$	·895	·1623	·1645	Maximum.
" " " ..	5 $6\frac{3}{16}$	8·80	·1595	·1617	..
" " " ..	5 $6\frac{3}{16}$	8·80	·1595	·1617	..
" " " ..	5 $6\frac{3}{16}$	8·85	·1550	·1570	Minimum.
" " " ..	5 $6\frac{3}{16}$	..	·1591	·1612	Mean of 4.
Yellow brass	2 $9\frac{1}{8}$	·5	·1811	·1839	..
Copper	7 $10\frac{7}{8}$	1·54	·1948	·1980	Minimum.
"	7 $5\frac{1}{8}$	1·465	·1972	·2005	..
"	7 $5\frac{1}{8}$	..	·1972	·2005	Maximum.
"	..	..	·1964	·1996	Mean of 4.
Lead (mould).. ..	2 0	·21	·1050	·1059	..
Zinc cast in iron ..	2 $0\frac{3}{16}$	·455	·2257	·2301	Minimum.
" " ..	2 $0\frac{3}{16}$	·465	·2307	·2352	Maximum.
" " ..	..	..	·2282	·2326	Mean of 2.

The amount of clearance to be left in the mould is much larger in hand-made green-sand moulds, and also with large and heavy patterns, or those which are difficult to draw, than in machine-made moulds, where the difference in size between the pattern and the casting, need be little more than sufficient to make up for the contraction of the metal on cooling.

There being so many elements of complication, it would be impossible to give any absolute rules or formulæ, sufficiently simple for an ordinary skilled workman to easily understand and remember, in the haste of every-day practice, when nearly every separate pattern that has to be made brings into play different conditions requiring special arrangements.

TABLE III.—CONTRACTION IN CASTING SPUR WHEELS IN CAST IRON (BOX.)

Extreme Diameter of Wheel Casting.	Pitch in Inches.	Width of Teeth in Inches.	Contraction: Total in Inches.	Contraction: A Foot: Of Casting.	Contraction: A Foot: Of Pattern.
ft. in.				inches	inches
10 $2\frac{3}{8}$	$3\frac{1}{2}$	12	1·08	·1059	·1040
6 $2\frac{9}{16}$	$3\frac{1}{4}$	9	·54	·0893	·0886
6 $1\frac{3}{8}$	$3\frac{1}{4}$	11	·375	·0613	·0610
5 $5\frac{9}{16}$	$3\frac{1}{2}$	11	·345	·0631	·0628
2 $11\frac{7}{8}$	$3\frac{1}{2}$	12	·11	·03896	·03884
2 $4\frac{15}{16}$	$3\frac{1}{4}$	9	·115	·0397	·0396

One of the most important points upon which success depends is the allowance to be made for contraction, the extent of which, as before mentioned, varies with the shape, size, and material of the casting. The allowance is nearly always made by the workmen in the dimensions of length only, although undoubtedly a similar contraction of the metal takes place, to a somewhat smaller extent, in the other dimensions of the casting. In the majority of cases, where the casting is a complete article in itself, perfect accuracy is not imperative. When, however, the casting is intended to be fixed together with other portions to form an engine, for instance, it is necessary that it should be true in shape and dimensions, and free from flaws and air holes. In cases where many castings have to be made from the same mould, the first should be carefully examined, and any little errors can then be rectified in the mould before again pouring.

In dry sand or loam moulds this trimming can be managed to a nicety; where they are too

slack, by laying on successive coats of clay and blackwash; and where they are too tight, by carefully rubbing away some of the sand or loam.

When numerous articles are required to be alike, a metal casting is frequently used as the pattern, as being more durable than wood. In this case a wooden pattern is first made, in which there is an allowance for what is called the double shrink, that is, the contraction of the metal pattern from the wooden pattern, and the contraction of the ultimate casting from the mould which has been formed upon the metal pattern.

The shrinkage sideways and endways of a casting 4 in. or less in size, is compensated for by the shake in the sand given by the moulder to the pattern, in order to extract it from the mould. In very small castings requiring to be of correct size, allowance should be made in the pattern for the shake of the pattern in the sand sideways, say about $\frac{1}{32}$ in. less than the length required.

In extensive works many forms of wood-working machines, specially adapted for this class of work, are used. A useful adjunct also is a steam glue oven. It can be arranged in various ways. The pressure these ovens should stand is 60 lb. to 1 in. without leakage, but the steam chamber must be tested considerably beyond this.

Detached letters and numerals, made in malleable cast iron, are also of great service; they can be readily bent cold to fit any curve. The sizes up to 2 in. high commonly have short spikes cast in the back, so that they may be fastened readily on to wood patterns of any description. The larger sizes have countersunk holes for screws.

The principal materials used in the various branches of moulding are, sand of various kinds, clay, blackening, coal-dust, and cow-hair.

The material of which the mould is constructed must allow of the passage of air and gases, which are generated within it at the time of pouring, but must also be of a sufficiently compact nature to resist the pressure of the liquid metal, and to prevent its exuding through the pores. It must be capable of bearing the very high temperature at which iron is poured, without being affected by it, and it must not be of a nature likely to set up any chemical action with the molten metal. It must be easy to part from the casting, and must give a clean, smooth surface to it.

Sand is superior to all other substances as a material for forming moulds generally. The hot metal has no chemical action upon it, and it acts well as a conducting medium for the air expelled from the mould, and for the gases generated by the action of the heat. And it possesses considerable adhesiveness when rammed together, sufficient, indeed, to make it retain its form against the pressure of the melted iron; and, moreover, it is easily made to conform itself very accurately to the surface of the pattern imbedded in it.

The higher the temperature of the metal to be cast, the more difficult it becomes to comply with the necessary conditions in the sand. Cast iron is poured at a higher temperature than most other metals which are cast, except steel, the moulds for which are prepared in a special manner.

The locality of many an important foundry has been determined by the proximity of suitable moulding sand in large quantities.

The sand of the London basin is among the finest in England. It is universally employed in the manufacture of fine goods, as grates, fenders, and the like. The sand in the neighbourhood of Falkirk is coarser and more open in the pores, which unfits it for such work. It is employed for casting hollow ware. The Belfast sand is finer than that from Falkirk, and is used principally for fine machinery castings. It is also sometimes used for facing the moulds of ornamental work, to give a fine surface. It is, besides, excellent for hollow moulding, when it is mixed with the Falkirk sand. Derbyshire, Shropshire, Lancashire, and Cheshire, and various places in Europe and the United States, produce excellent sands.

One great desideratum is, that these sands should not be liable to what is called burning, in use, when they will only do duty once with any safety. This defect arises from the crystals in the sand not being sufficiently refractory to stand a high temperature, owing to which they break up into fine dust, which, if wetted and used again, will set in a close and compact mass, and spoil the casting.

Parting sand should be of a lighter colour than the moulding sand, and should be clean, fine grained, and of uniform texture, free from salt and chalky matters. Red brick-dust, fresh free sand, or blast-furnace cinder, finely pounded, may be used. In any case, the substance used must be one which does not retain moisture. Green-sand moulds are faced with oak-charcoal dust ground to an impalpable powder. Dry sand or loam moulds are faced with wood-charcoal dust ground to powder, or with a blackwash consisting of coal-dust mixed with water.

Moulding sand is always mixed damp, with a proportion of coal or charcoal dust; ground bituminous, or rich, hard splint-coal, being preferred. Where wood fires are employed, the soot from their flues is occasionally employed for this purpose.

The proportion of carbonaceous matter to the sand varies, and depends partly upon the quality of the sand itself, and partly upon the uses to which it is to be applied. One part coal to 10 of sand, and 1 part coal to 15 sand, are about the maximum and minimum proportions for the sand floor of the moulding shop. In facing sands, the variations range over a large field; from 1 in 10 to 1 in 20 may be considered the maximum and minimum proportions.

Every time the sand is employed, that portion of the coal-dust in it which is contiguous to the casting undergoes a chemical change, which is called being burnt, by the moulder, consequently frequent additions of fresh coal-dust to the sand are necessary. For this purpose the sand should be damped, and dug over, and allowed to get cool, and then the new coal-dust must be well mixed in with it.

Blackening and coal-dust are employed to resist the penetrating action of the iron on the sand. Blackening is simply charred oak-wood ground to powder. Oak charcoal is superior to all other ordinary wood charcoals for the purpose, as it is the heaviest. Other wood charcoals are apt to become disengaged from the surface of the mould to which they are applied, and to float in the iron while liquid, which of course defeats the object of their use. Ground plumbago forms a good blackening for high-class work.

Oak charcoal being expensive, many attempts have been made to substitute other materials for blackening; none of these have been very much employed except carbonized peat. A method of treating peat for this purpose was described by C. E. Hall in a paper read before the Society of Engineers in 1876, and it was then stated that peat blackening had been used for light and heavy castings and cores, with marked success.

In large castings, the blackwash on the face of the mould should be proportionately thicker than for small ones, to allow for the longer continuance of high temperature to which it is exposed, but even this precaution will be of little avail if the moulding sand is not of a very refractory nature.

For castings, where the temperature of the metal is likely to exceed that of melted cast iron, it is advisable to make a special facing of quartz and refractory fireclay. An infusible facing sand is made of the siliceous ganister and fireclay wash; dry and screen, then add coal-dust, ground charcoal, or plumbago.

After sand, loam is the founder's great material. As with fireclays, a chemical analysis of all loams and clays should be obtained, before any large purchases of these materials are made. An experienced moulder will generally be able to form a pretty correct judgment as to the qualities of these articles, testing them by observing their plasticity or capacity for taking and retaining impressions. The clay generally used is either calcareous or ferruginous; when it contains a considerable proportion of sand, the mixture is called loam. At a red heat these substances part with their combined water; most of the chalky clays fuse at the melting point of cast iron, or become vitrified. The ferruginous clays, or such as contain alumina and silica, are more refractory. Pyrites and limestone are objectionable in clay or loam, and flinty pebbles should also be removed before the clay is ground in the mill.

The clay should not be allowed to get hard and dry in the store or stack, as it is much more difficult to get it to a proper consistency afterwards. Lime and alkalies are to be avoided, and any clay containing more than about 5 per cent. of carbonate of lime should be rejected.

Clays which do not contain any sand require to have some ground in and mixed with them; and nearly every clay requires a certain proportion of sand to be added to it when ground up.

For giving the necessary porosity to loam, a number of substances are added to it. Amongst them may be mentioned powdered coal and coke, horse-dung, straw, chaff, plasterers' hair, bran, and chopped tow; the material employed must not be cut or ground up too fine, or it will lose some of its binding power, and it must be uniformly mixed throughout the mass of the loam. These substances are only added to that part of the loam intended to be used for the body of the mould, and not to the loam which is used for finishing the face of the mould. The loam mill has, therefore, two functions to perform, namely, grinding and mixing.

An ordinary mortar-mill is generally used for the purpose, but there are several modifications in detail, which are of advantage for loam-grinding purposes.

A greater portion of the mixing of the materials used for fine work is done by hand, and this is especially the case with facing sands, which a careful moulder superintends himself.

Loam is usually wetted with cold water when in the mill, but in the winter it is found advantageous to use warm water for this purpose, or to blow waste steam over it from a jet pipe, as it not only facilitates the grinding and mixing, but considerably assists the moulder in his work; as he *must* handle the loam, if it is mixed with water only just above freezing point, his hands get so benumbed as to seriously hinder his operations, besides causing him unnecessary pain and inconvenience. Of course by the time the loam is delivered into the moulding shop, it will have lost a considerable portion of its heat, yet it can be readily delivered at a temperature of between 60° and 70° F., beyond which it is not necessary or advisable to go, as at much higher temperatures the loam loses some of its cohesiveness.

If the loam has to be left in the open all night during frosty weather, it should be covered with coarse matting or bagging to prevent its freezing, which, however, it is much less liable to do if it has been mixed with warm water. In cases where a foundry possesses its own clay pit, the clay is frequently weathered by being cut up and exposed to the action of the winter's frost, until it is required to be ground and mixed; this somewhat facilitates the latter operation.

Where unbaked clay-bricks are required for loam moulding, dies may be prepared of various sizes and forms likely to be useful, as a stock of these bricks saves the moulder's time in cutting and trimming his moulds.

The power of conducting heat is considerably less in red-hot iron than in copper and brass, and therefore the moulds for the latter require to be in a drier condition than those which may be used for iron. Ironfounders' moulds are therefore more moist, and the sand they use is coarser and more porous than that of the brassfounder.

Moulds made of metal are frequently employed for casting tin, lead, pewter, zinc, and types. Brass or bronze moulds are generally preferred for such purposes to iron moulds, as they do not corrode, and retain a better polish. Such moulds are constructed on the same principle as sand moulds. If a metal mould is divided into several parts, each part should be provided with a long handle to protect the hands from the heat of the mould. All the parts must be accurately fitted together, and kept in position by means of lugs and pins, or by wedges. Gently heat the mould before pouring metal into it; this is especially necessary when casting metals having a low melting point, as they have not much heat to part with between the melting point and the temperature of solidification. Polish the mould after each cast, and rub over with a rag and oil or tallow so as to slightly grease the face of the mould. Sometimes a film of sandarach, beaten up with the white of egg, is applied, particularly for alloys. For single metals oil or fat is preferable.

Some few objects are cast in open moulds, so that the upper surface of the fluid metal assumes the horizontal position the same as other liquids. As a general rule, however, the metals are cast in close moulds, so that it becomes necessary to provide one or more apertures or gates for pouring in the metal, and other apertures to allow for the escape of the air displaced and the gases generated by the inflowing metal.

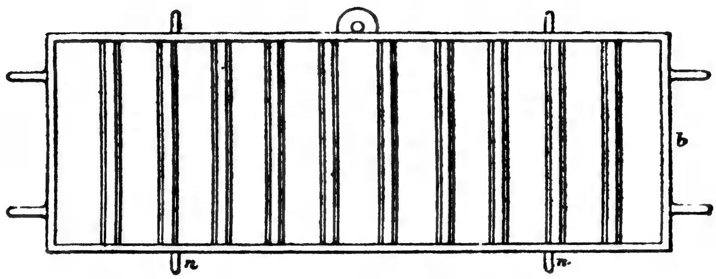
When these moulds are made of metal, they must, except for chill castings, be heated sufficiently so as not to chill or solidify the fluid metal too hastily; and when moulds are made of earthy matters, although moisture is required in their formation, it must all, or nearly all, be evaporated out before they are filled with molten metal, or explosions of steam will occur.

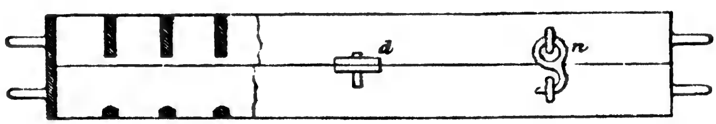
Moulds consisting partly of loam or sand and partly of metal are frequently employed. Small wheels, bushes for cart-wheels, and the like, receive their bore by being cast over an iron or steel core. Such a core iron is a little tapered, to admit of its being freed from the casting by a smart blow of the hammer.

The casting must not be allowed to cool down entirely before the core is removed. It is generally removed when the casting is hot, but so far cooled as to resist the drawing out of the core iron.

In processes of green-sand and dry-sand moulding, boxes or flasks, Figs. 1257 to 1260, are always employed, the purpose of which is to contain the sand in which the pattern is moulded. These boxes

1257.

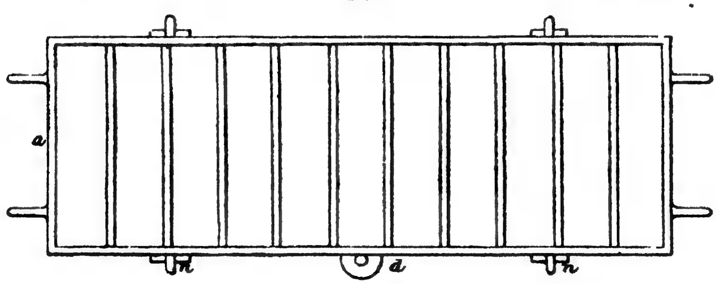


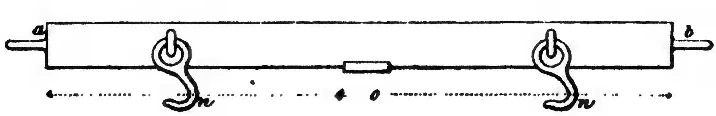


1258.

are, for convenience, of various sizes. If there is a great or constant demand for castings of one form, boxes are made expressly for them, corresponding in form. By this plan a saving of labour is effected, as the ramming up of useless corners is avoided. For general purposes boxes are made rectangular, and in two halves. These boxes have neither top nor bottom, but each half-box, or, more correctly, each box, is composed of an outside rectangular frame *a b*, which is generally 3, 4, or 5 in. deep, for the lighter flat moulding. They have transverse ribs joining the opposite sides at equal distances of

1259.





1260.

4½ in. between them. The rougher these boxes can be made the better; they hold the sand more effectually, and accordingly, in casting the boxes themselves, the patterns for them are simply laid in the sand on the ground, and after being rammed are drawn out. There is no blackening used for the surfaces of the moulding, and thus the iron enters the pores of the sand and roughens.

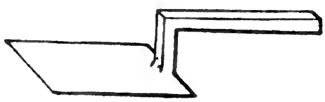
As there is no covering for the mould, it being exposed to the air, this mode of casting is called open sand casting; the exposed surface, however, is very irregular and rough; this method is used

only for moulding boxes, where the roughness is a virtue, and for articles of a coarse nature. Wooden boxes or flasks are also in use, but not commonly in large works. In these nails are made to project inside to increase the adhesion of the sand, and the same plan has been applied to iron boxes, but it is not a good one.

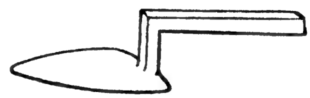
The ribs of the upper boxes are not so deep as the outside frame. They are generally an inch less deep to allow a depth of sand over the pattern that is imbedded in the sand of the lower box. The frame of this box, called the drag-box, is the same as that of the upper, but the ribs are much shorter and thicker, as it is not required to be moved about and inverted like the upper one; besides, it allows a much more available depth of space for the moulding of the pattern. As the lifting and shifting of these boxes, when small, is usually managed by two men, they have two snugs or handles at each end, seen in the figures, by which they are held. They have also usually three hooks and eyes *n n*, Fig. 1260, and three pins and holds to receive them, arranged alternately along the sides, there being two on either side and one over the other. The pins are fixed on ears *d d d*, cast on the sides of the drag-box, and pass through holes made in ears in the upper box, which correspond, so that the boxes, in being placed together, must always have the same relative position. These pins are often chilled to make them more durable, and one made square while the others are round, which ensures accuracy of position. The hooks and eyes hold the boxes tightly together for the casting.

Figs. 1261 to 1272 represent the different kinds of tools employed by flat moulders in the execution of their work. Fig. 1261 is the trowel, the instrument in most frequent use. There are various

1261.

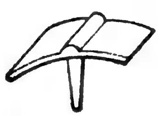


1262.

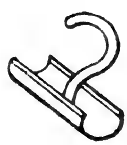


sizes of it used, from one-fourth to 2 in. broad in the blade, and 3 in. long generally. The purpose of the trowel is to clean away and smooth down the surface of the sand, to press down and polish the blackening, repair injured parts of the moulding, and so on. Fig. 1262 is another form of trowel of a heart shape. It is particularly employed for entering acute angles in a moulding, into which the square trowel evidently cannot go. Fig. 1264 is another form of tool for managing hollow im-

1263.



1264.



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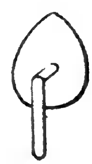
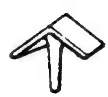


1266.

1267.



1268.

1269.

pressions in the sand. Fig. 1271 is the form of the sleeker and cleaner. As the trowel is applicable only to open, plain surfaces, this tool is used for cleaning and smoothing sunk surfaces in the sand which the ordinary trowel cannot reach, as the impression of a flange, or of any flat part of a pattern presented edgewise to the sand. The upper end is applied to the sides of such an impression for sleeking or smoothing it, and the under end goes to the bottom, where it is used both for taking up loose sand lying there, and for pressing and smoothing down the surface. It is to be noticed, too, that the upper end is presented edgewise to the direction of the spade at the under end, so that when this is employed at the bottom of a deep recess, the upper end stands sideways to the sides of the recess, and permits free motion.

Fig. 1272 is the first rammer; it is about 4 ft. 6 in. long, and its under face is about 2 in. by 1 in. Sometimes the upper end, by being tapered off, is made to serve for forcing holes in the sand. Fig. 1270 is the second rammer, for finishing the work of the first. It is round in the face, about 3½ in. diameter, with a wooden shank of convenient length,

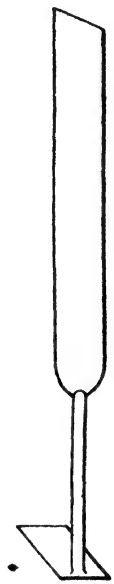
Figs. 1263 to 1269 represent the forms of the cast-iron sleekers employed in the operations of hollow moulding. Figs. 1266 and 1267 are of the convex and concave sleekers for corresponding surfaces. Figs. 1268 and 1269 are tools with double plano surfaces at certain angles with each other. Of these there are a variety, having their planes at different angles, to suit the various salient and retreating angles that occur in mouldings. Fig. 1263 is a sleeker for the impressions of beads, and Fig. 1269 serves to smooth flat surfaces generally. All these have small studs attached to them which serve for handles.

Besides these tools, shovels are used for working the sand, sieves and riddles for refining it, and bellows for blowing off loose sand from mouldings; pots for holding the parting sand and the water used in moulding, swabs for applying this water to the mouldings, being simply tufts of tow brought to a point, and separate linen bags of peasemeal and blackening, through the texture of which these

materials are shaken on the sand. There are also piercers or prickers, as they are termed, being pieces of thick iron wire sharpened at one end to a point, for piercing the sand to let off air, and steeples and chaplets, pieces of iron of various shapes, to support cores or other parts of the mould. Moulders' nails are used for the same purpose, and range from 2 in. to 6 in. long in the shank, with flat heads of various shapes and diameters; a circular head $\frac{5}{8}$ in. diameter, and one shaped like a parallelogram $2\frac{3}{4}$ in. by $1\frac{7}{8}$ in. being common extremes. The heads of these nails are often made on a curve, or concave, to adapt them for supporting circular pieces.

1270.

1271.



1272.

The art of moulding may be divided into two great divisions; sand moulding and loam moulding. In the first, patterns of the articles wanted are employed in forming the mould; in the second, the ordinary patterns are dispensed with, the objects of this division being heavy castings of a regular form; as cylindrical bodies generally, and other circular ware, such as sugar pans and gas retorts.

Large square vessels, water tanks, for example, may also be made by a process of loam moulding. Dry-sand moulding is generally employed for the making of pipes, columns, shafts, and other long bodies of cylindrical form. It is firmer, and better adapted to purposes of this kind than green sand. The material of dry sand is the loam already used in loam moulding, called pit sand, mixed in the mill with an addition of rock sand. It is named dry sand, in contradistinction to green sand, because, after being moulded, it must be dried by heat to fit it for the purpose, whereas the latter is employed as it comes from its native bed, new and damp; the dampness, indeed, is assisted afterwards when necessary, as a certain degree of it is always requisite; but it must not be wet, or approach that condition.

The operations of green-sand moulding are generally recognized under two great classes, hollow moulding and flat moulding. The former includes pots, frying-pans, and every other kind of cooking ware, of a light, dished form. The latter class is very extensive, and is so termed in opposition to hollow moulding, It includes all objects of a flat nature, plate-moulded goods, the various parts of grate furniture, and other ornamental work generally, stoves, smoothing irons, all kinds of machinery that do not fall under the head of loam or dry-sand moulding, for instance, all the cast-iron work of spinning and loom machinery. In fact, a kind of subdivision exists, known as job moulding, a homely term, including machinery generally and the heavier kind of work, distinguishing them from the ornamental and other lighter work. A steam engine affords in the parts of it examples of the three kinds of moulding. The steam cylinder and air pump which are round, and the condenser which is often square, are instances of loam castings; the flywheel, shaft, and the single columns supporting the framing, are examples of dry-sand casting, and the beam, if a Cornish engine, bed plate, and connecting rod, if of cast iron, are referable to the heavier green-sand casting.

The front of an old-fashioned register grate is a familiar instance of light, flat moulding. Its construction is that of two jambs joined at the top by a cross piece. On the back, or inner surface, it is quite flat, and is ordinarily ornamented on the face with raised figures of flowers, or the like. A box is selected that will receive the pattern, and have a few inches to spare, that the pattern may be completely surrounded with sand. The pattern is then laid down, either on the surface of the sand, prepared in the upper box, and which is then termed the false part, which is lying inverted on the ground, or on a flat board of sufficient size to support it in all parts. In either case the pattern is laid down on its back. There is next thrown over it a layer of fine sand an inch deep, constituting the facing of the moulding. It is passed through a sieve to detain the coarser parts. Then upon the board, or upper box, the drag-box is placed in its proper position in respect to the pattern.

It is necessary to spread the facing of sand before laying down the box, as its ribs prevent the equal distribution of sand. An additional quantity of the common sand is passed through a riddle, which saves the small stones and other refuse in the sand, and the whole is now rammed down by the flat rammer as equally as possible. The box is again filled up with sand and rammed all over with the round-faced instrument. When the sand is properly set and squared flush with the surface of the drag-box, the whole is turned over, avoiding sudden shocks of any kind, which tend to loosen the sand, and well bedded on the ground with the drag-box undermost. The upper box, or the board, as it may happen to be used, is lifted off, and the temporary bed of sand in it is destroyed. The upper surfaces in the drag-box, and of the pattern imbedded in it, are cleaned and smoothed by the trowel, so that the surface of the sand is made flush with that of the pattern all round, and also meets the edges of the box. This forms the parting, or place of separation of the sand in the two boxes; and that they may afterwards separate properly, dry sea-sand is freely sprinkled over the parting surface, and has the effect of preventing the adhesion of the lower layer of sand to that which is superimposed, by entering and drying its pores. The upper box, which, when made up the second time, is called the cope, is now laid on the other, guided by the pins, and both are

fastened together by the hooks. In bringing them together their meeting surfaces ought to be cleared of sand, so as to make them bear freely and steadily. Preparations are now made for the construction of the gates, or passages for the iron from the external surface into the mould. In the moulding of a register grate front there are usually four gates, into which the iron is poured simultaneously.

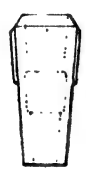
To provide for the gates to the moulding, four taper pins of wood are stuck in the sand of the lower box, at a short distance from the pattern, projecting upward between the ribs of the upper box. Sand is, as before, thrown into this box, covering the flat side of the pattern, and is rammed between the ribs until the box is filled flush with itself. The pins are now withdrawn, and the holes formed by them are widened at the top into bell-mouths, to receive the iron more rapidly, and are well smoothed there to prevent the metal carrying in with it any loose sand. The upper box is now taken off with care, to preserve the impression of the upper side of the pattern, and the edges of the moulding of the box in contact with the pattern, are wetted with the swab to make the sand at these corners the firmer, and to prevent crumbling on withdrawing the patterns. The moulder has to repair damages by adjusting disjointed parts, and making up fractures by the addition of sand. The blackening has now to be applied, and it must be by some means pressed down upon the mould at every part, and made to adhere to its surface. To effect this, peasemeal is used. It is first dusted thinly over the surface of the mould. It rapidly absorbs the damp of the surface sand, and is converted into a pasty matter. The blackening is next dusted over the newly formed paste, and over all, the pattern is placed in its position and pressed down. Thus the blackening is made as smooth as the pattern, and is at the same time held well down to the sand. Channels are now scooped out of the surface of the sand, joining the gate holes to the moulding; and if the pattern be thin, each channel is widened as it joins the mould, to afford a sufficient inlet for the iron. They are slightly swabbed round the mouth to strengthen the edges against the abrasive action of the iron.

Having finished the moulding, and got it in order for the reception of the iron, the upper box is finally put on the under one in its place, and fastened down upon it. All is now ready for the pouring of the iron.

Before dismissing the subject of light moulding, one other example may be described, introducing the use of three boxes for a moulding. The instance referred to is the moulding of the cast-iron bushes, which are fixed into the naves of the wheels of waggons and other vehicles, to sustain the wear of the axle.

Fig. 1273 is an ordinary bush for cart-wheels. The dotted lines show the form of the interior, which is a tapered hole. At the middle of the length, a chamber is formed in the bush so as to surround the axle, its object is to contain the grease for lubrication. These bushes are always cast in pairs, and the cores for them are cast-iron pins, having the form of the axles for which

1273.



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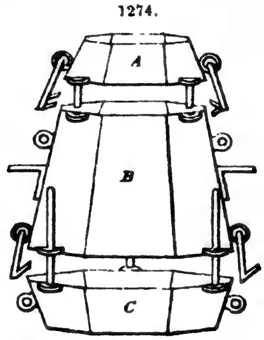
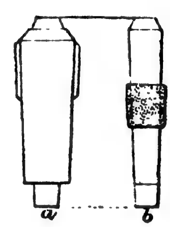


1275. 1276.



they are intended. These pins, which serve for many successive castings, are turned and polished in the lathe, for the purpose of communicating a smooth surface to the interior of the bushes, by which the expense is avoided of boring them out, which would be necessary were sand cores employed.

The pattern of the bush, Fig. 1275, is solid, and has, in addition, a core-print on each end to steady the core. Fig. 1276 shows the core extended at the ends in correspondence with the prints. Round the middle of its length a thickness of sand is wrapped, to form the grease chamber in the bush. This part is made of sand, so as to be separable, and thus allow the core pin to be driven out of the bush when cast.

The box in which the bushes are cast consists, as already mentioned, of three parts. The length of the middle part is made the same as that of the bushes, between the small end and the tops of the feathers. The parts are octagonal in plan, as in Figs. 1274 and 1278, where A is the top, B middle, C bottom.

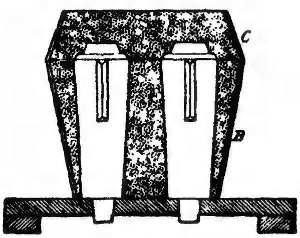
In proceeding to mould the pattern, a flat board is laid down level, with two holes in it at a suitable distance from each other. Upon this board a pair of bush patterns are set down on their small ends, the points passing through the holes in the board to keep the pattern steady. The box B is inverted, laid down over them and filled with sand, which is rammed about the patterns level with the tops of the feathers on them. The box C is now fixed on and rammed with sand. Fig. 1277 is a sectional view of the boxes and their contents at this stage of the process.

The two boxes together are inverted and set down, the box A is fixed on the uncovered end of B, and it likewise is rammed flush with sand. Two holes are next pierced downwards in the sand with the handle of the rammer, one on each side of the patterns. One of them extends just through

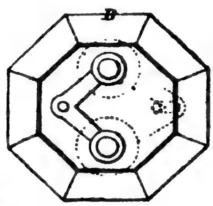
the box A, and the other reaches down to the box C. A and B are lifted together off C, and turned over; the patterns loosened by tapping are next drawn out. A and B are then separated. Two prepared core pins are next set, as vertically as possible, into the recesses left by the prints in the sand of the lowest box; on the surface of the sand, at each end of the box B, channels are cut joining the gate holes, made by the rammer to the two mouldings, in such a manner that the short gate will be connected with the upper end, and the long gate with the under end of the mouldings. B is lowered over the cores and fixed to C, being directed by long guide pins at the side. A is next replaced, guided also by pins and fixed to B. It must be placed with care, as the upper ends of the cores are at the same time entering the recesses made by the prints, and thus the cores are secured between the boxes A and C.

Fig. 1279 is an external view of the moulding as thus finished, with the interior arrangements in dotted lines. Fig. 1278 is a view of the upper and under ends of the middle box, showing the

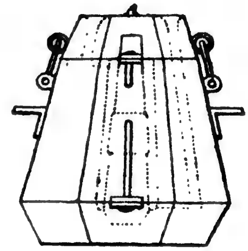
1277.



1278.



1279.



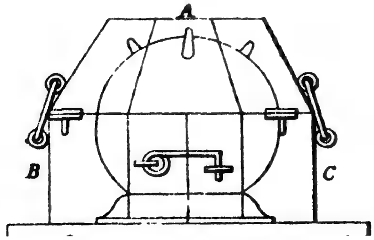
gate channels. The iron is poured into the long gate, falling against the bottom of it, the force of the iron is broken, and it runs gently into the mouldings, rising within them till they are filled, when it passes into the short flow gate, as it is termed, from which it issues, carrying off the refuse it may have gathered in its passage. Blackening is not applied to these moulds, as their roughness is of no consequence.

The gates for any casting, as we have said, are a matter for particular care. In the language of the shops, all the passages leading the fluid metal into the mould are called gates, each of which, however, has its own peculiar name, hence the large opening into which the metal is first poured is termed the pouring gate. The recess below, or in connection with the pouring gate, for skimming the iron, is termed a skimming gate; the little passages from the skimming gate to the mould are sprue gates, usually sprues only; and those openings by which the supply of iron is kept up after the casting is poured, are called feeding gates.

The form, size, number, and proper arrangement of either or all of these, have a decided effect upon the soundness and cleanness of the casting to which they appertain, and should be arranged as to size and position with especial reference to the size, shape, and character of the work in hand.

The distinct objects of hollow moulding are comparatively few in number and small in dimensions; there are moulding boxes for them, individually of corresponding shape, generally manageable by one person. Boxes in two, three, or four parts are employed as the necessities of the case may require. Take, for example, the moulding of a three-legged pot, Figs. 1280 to 1283. The body of it is nearly spherical, drawn in at the neck and opening towards the brim. It has two ears at the neck, by which it is moved about when in use, and three feet on the bottom. The pattern is an exact model of the pot, being in two halves separating vertically. The patterns of the feet and ears

1280.



1281.

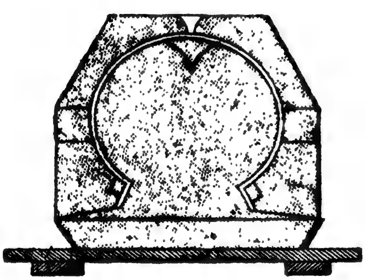
are also loose on the body of the pattern, fitting to it by pins. To form an original pattern, the plan usually adopted is that of moulding in loam. The rough cast pattern is chucked in the turning lathe, and turned within and without to the required form and thickness; four longitudinal rows of small holes are bored through the pattern, at equal distances round it, by which its thickness at any part may be always ascertained. Having been smoothed and polished, the pattern is taken from the chuck, and cut in two equal halves, in which holes are bored in the proper positions for receiving the pins of the ears and feet. The pattern is moulded in a box, consisting of four parts, the top A, the two cheeks B C, and the bottom D. The division into parts is the same as that of

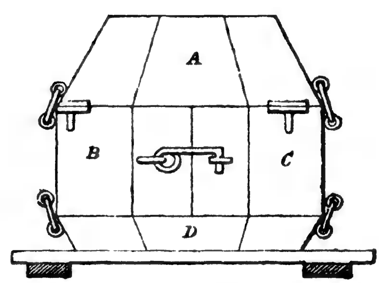
the moulding box for axle bushes, supposing the middle part divided vertically in two, corresponding with the cheeks B C. The pattern being moulded in an inverted position, the top A is made to enclose the bottom of the pot, as far up as its largest diameter; the cheeks B and C enclose the remaining portion of the pot, and the bottom D serves to close up the mouth of it.

The two cheeks are first laid down on a level board and linked together; the pattern is then laid down on its brim within the cheeks, being raised off the board by a slip of wood, of such a thickness as to bring the largest diameter of the pot to the level of the upper edges of the cheeks. The patterns of the ears are attached, and sand is rammed in round the pattern, flush with the cheeks, making the parting surface on the centre of the pot. The surface having been sprinkled with parting sand, the top A is put on, led into its place by guide pins and fastened to the cheeks. Sand is again rammed in to the level of the mouth of the pot, the patterns of the feet and the gate pin being set in their places in the course of the ramming of the sand, Fig. 1280. The whole is next inverted, and the board and slip of wood removed. The surface of sand round the brim of the pattern is smoothly sloped off to the edge of the box forming the parting surface, and the bottom D is fixed on. It is also filled with sand. The body or core of sand filling the interior of the pattern is pierced in several places with a pricker sent down to the pattern, forming thereby channels of escape for the air expelled by the metal introduced. The whole is finally inverted, D lying uppermost, and placed on a flat board with a hole in it to allow the escape of the air. The sand outside the pattern is sometimes pricked, though this is but of little importance.

The part A is now separated and lifted off, carrying the feet and pin with it. The cheeks B C are next separated horizontally, taking the ears with them; and the half-patterns are withdrawn from the core. The external and internal moulds thus exposed are sleeked up with appropriate tools, and blackening is dusted on them, and also sleeked up. The patterns of the feet and ears, and the gate pin are drawn out, the boxes B C are replaced exactly as before, and the box A above them, the whole being again bound together. The mouth of the gate is next formed and smoothed. The space occupied by the pattern is now vacant for the metal. Fig. 1282 is an external view, and Fig. 1283 a section of the box and moulding. In the section are shown the parting surfaces, and the slope of the under one.

All dished utensils are cast with their mouths downwards, and, in some cases the area of the mouth is so small, when compared with the largest diameter, as to render it necessary to bind down the core in the mouldings. For the iron lying so far in below the core, it tends by upward pressure





to lift the core off from its base. This binding is effected by burying an iron rod in the core, having on it a cross at the end to give it a hold of the sand, the outer end being locked to a transverse piece which bears on the edges of the box.

The metal requires to be at a high temperature for hollow moulding; for so quickly does it cool, that the brim of a moderate-size pot sets even before the mould is filled. While yet red hot the casting is taken out of the sand, and the gate piece knocked off at a certain stage of the cooling, as when this is done too soon the gate does not break clearly off, and when delayed too long, it often carries off a piece of the bottom of the pot with it. With a view to provide against this, the pot is made considerably thicker at the centre of the bottom. Flat gates are formed for flat-bottomed ware, frying-pans for example. They are wide at the mouth to receive the iron the better, but taper like a wedge toward the moulding, so as to be easily separated from the casting. By being of considerable extent, flat gates conduct the metal more speedily to the different parts of the mould.

A great improvement was effected in this class of moulding by the arrangements introduced and employed by J. Jobson, before referred to at p. 1540 of this Dictionary.

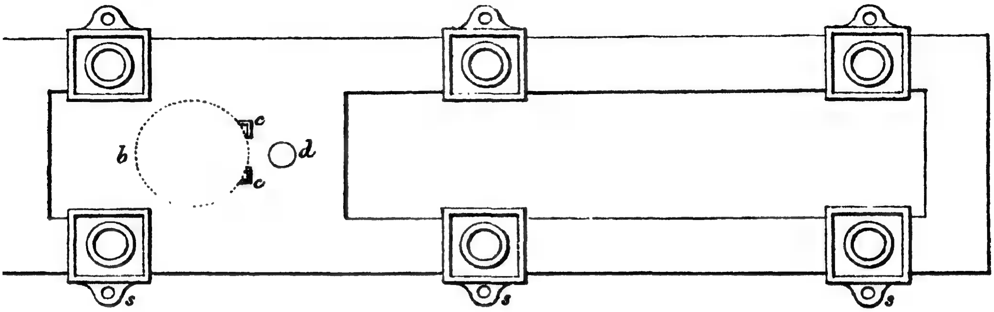
For heavy green-sand moulding, powdered coal is introduced into the sand, in a state of simple mixture, to assist the blackening in resisting the penetrating action of the iron. The proportioning of the mixture is a matter requiring considerable judgment, and to obtain the best result the ingredients should be mixed, not only in such proportions as are suited to the body of the metal to be cast, but also as uniformly as possible.

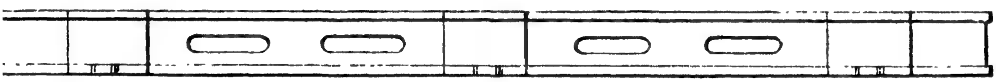
For large castings, the bed of sand which forms the floor of the foundry is commonly used for constructing the moulds, serving thereby the purpose of the drag-box. The chief defect entailed by this method, which is indispensable in some cases, is that the moulder has to work in a very uncomfortable position.

Fig. 1284 is an external view of the bed-plate, showing the upper surface, of an early form of high-pressure engine, by no means a form to be imitated, but merely given here for illustration. It was arranged to maintain six columns, surmounted by an entablature. At one end, b, a flat form

for supporting the cylinder is cast across the plate, stiffened by a deep flange at the edge. The position of the cylinder is indicated by the dotted circle. When the cylinder was set in its place, the apertures *c c* formed continuations of the exhaust steam passages, they were joined into one short branch pipe below the platform; *d* is a circular passage for the introduction of the steam into the valve chest. It is projected downwards to the level of the mouth of the eduction pipe, both

1284.



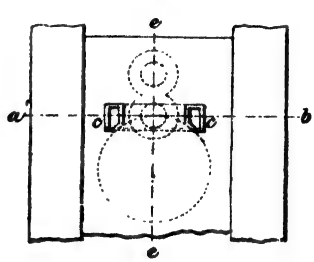


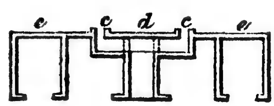
1285.

passages terminating in one large flange, by which the respective pipes leading to them are connected.

Fig. 1286 is a plan of part of the bed plate, including the steam-ways, showing in dotted lines the exhaust passage and the flange. Fig. 1287 is a vertical section of the plate and the exhaust passage at the line *a′ b′*, Fig. 1286. The steam passage also is dotted in behind it. Fig. 1288 is another vertical section of the same, at the line *e e*, Fig. 1286, showing in section both of the passages *c d*.

1286.





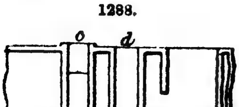
1287.

Fig. 1289 is a plan of another portion of the plate, showing the foundation for a column; Fig. 1290 being a vertical section of the same at the line *a″ b″*, Fig. 1289. It thus appears that the bed plate is hollow within, and it possesses the form of section, Fig. 1287 all round, interrupted only by the sockets for the feet of the columns. It is a general practice in founding, to dispose of the moulding so that those parts of the casting towards which the greater quantity of metal exists, may be undermost. In this way greater security is found for the soundness of castings at the more important parts.

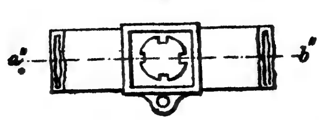
Now the bed plate is, for the most part, entirely open on the under side, as may be seen on referring to section, Fig. 1287; and this is particularly the case in modern examples. It ought therefore to be cast with that side uppermost, according to the preceding statement.

The pattern of the bed plate, of the same form externally, is not made open like the bed on the under surface. Neither are the oblong blank spaces, shown in the sides, executed in the pattern; its cross section at every point is a four-sided figure. This form of pattern in the sand will, of course, leave a plain open space of the same breadth as itself. Cores of sand, of the form of the internal void, must therefore be introduced into the moulding to complete the figure of the casting. Fig. 1291 exhibits the under side of the pattern. At *a* the patterns of the steam-ways are placed. They are not fixed to the surface on which they stand, but are simply prevented from shifting laterally by small pins or snugs. They are made solid, so that they too, like the plate itself, require to be cored out, and accordingly the prints for securing the cores

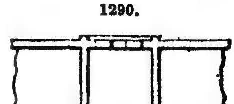
1288.



1289.



1290.



in their positions are added to the patterns of the flange, which itself is attached loosely to the pipe patterns. On the opposite side of the main pattern, prints are likewise fastened, to receive the cores for the column sockets, Fig. 1290, and to the snugs *s s*, to core out the holes in them.

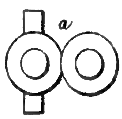
A level bed in the sand upon the floor, of sufficient extent, is in the first place prepared for the

pattern, which is then set down upon it and well bedded in its place. Sand is further laid in and rammed about the pattern on all sides, till it be brought up flush with the upper side, forming thereby the parting surface, on which the parting sand is strewed.

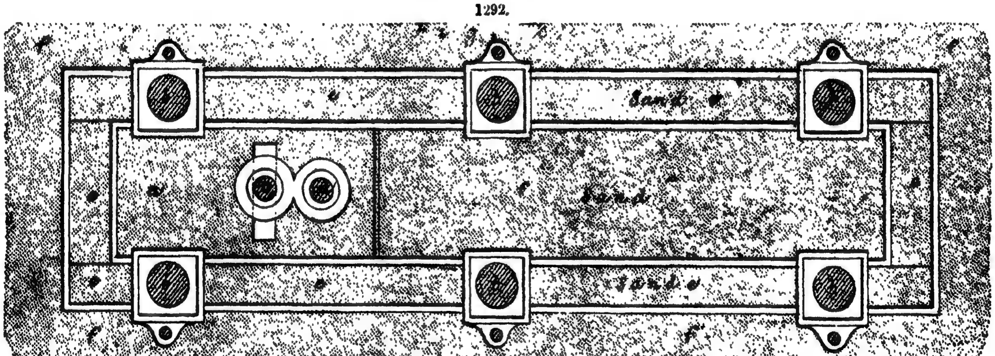
The next stage is to lay the upper box or boxes over the pattern, and to fix them in their places by stakes of wood driven into the floor, which also serve as guides to replace them accurately when moved. If there is not a single box large enough to embrace the whole of the pattern, two or more smaller boxes are placed end to end over it, resting upon the sand external to the moulding, and answering the purpose of a single box. The ramming of these is conducted in the usual manner, except at the end *a*.

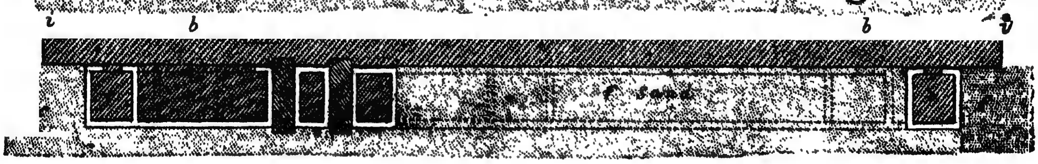
As the platform or cylinder plate is now on the under side of the pattern, the body of sand filling the space immediately above it, to the level of the upper side, must be lifted out to get the pattern removed. At the same time, the weight of such a deep body of sand adhering to that in the overlying box, would overcome the sand's cohesion, it would break away altogether. As the box is therefore incapable of carrying it with it, it becomes necessary to have this load of sand supported by independent means.

An iron frame is cast in open sand of the same form as the sunk space, but somewhat smaller, as allowance for the contraction of the casting, in the course of cooling, must be made to allow the



1292.





1293.

plate to be withdrawn, after the casting is executed. In cases where this precaution has not been sufficiently attended to, the jamming of the plate, enclosed on more than one side, has been the natural result, and sometimes the destruction of the casting by consequent fracture. In the centre of the frame, a sufficient opening is allowed for the steam-ways. This frame is laid in the bottom of the recess, and as its under surface now faces the moulding, it must be enveloped on that side in the sand, to protect it from the immediate action of the metal, afterwards poured into the mould. To assist its adhesion, the frame or plate is studded on the under side with numerous tooth-like projections, which are imbedded in the sand applied. Sand is now thrown in above the plate surrounding the steam-ways and well rammed, its parting surface being made flush with the upper edges of the pattern of the pipe flange in the centre, and of the contiguous body of sand forming the interior part of the moulding, their parting being just over the stiffening flange of the cylinder bottom. With this preparation the upper boxes are set down and filled.

There are prepared six moulding gates to the moulding, and eight flow gates. Of the pouring gates, or those by which the moulding is filled, two are placed along each side, about 4 ft. distant,

and two at the cylinder end of the moulding, while none are made at the other end. This unequal division is necessary on account of the heavier nature of the moulding at the cylinder end; the design of the whole being to have the moulding filled uniformly. The flow gates are distributed equally over the moulding. These will be again referred to.

Before lifting off the upper boxes, the pattern being now completely moulded, the latter is so far loosened in the sand, that this may not stick to it, and so spoil the operation.

After the box is removed, the plate and its overlying core of sand, as it may be termed, deposited at the recess of the cylinder end of the pattern, are lifted out of their situations by arms rising through the core, carrying with them the pattern of the steam-ways, which is at liberty to go, for, as we have already noticed, it stands loose on the main pattern. That pattern itself is not in one piece; the flange, which is separate, is lifted off towards the upper side of the core, and the remainder of the pattern is drawn out by the under side.

The parts of the mould, in the neighbourhood of the pattern, must now be pierced with small holes, executed by wires traversing the whole body of sand, with a view of rendering the moulding more porous, and of facilitating thereby the escape of the air and other gases; the mould is also watered along the edges to increase the coherence of the sand.

The pattern itself is taken out by lifting it in all its parts at once, by pins secured into it at several places, so as to be raised in a truly vertical position. This manœuvre is performed by several men. Unavoidable degradations in one or other of the two parts of the mould do occur, and these the workman repairs with damp sand by means of his trowel.

The moulding is next smoothed over the surface by the trowel, and a sprinkling of charcoal is then applied. It is, however, omitted for very large castings. Sometimes also, in order to avoid using too much charcoal, the surfaces are lightly dusted over with sand finely pulverized, through a bag. The moulding is now ready for the reception of the cores.

There are, first, the cores for the column sockets, of which there are six; then the cores for the intermediate portions of the bed plate, of which also there are six, there being two on each side between the socket cores, and one at each end; again two cores, for the holding down bolt-holes in the snugs at the bases of the columns, as well as for the holes that may be required for the bolting down of pedestals, and the like, to the bed. For all these there are simple prints sprigged upon the pattern at the proper places, the impressions of which in the sand serve to hold the cores securely.

As we have already remarked, the cores must be made not only of the exact size and shape of the vacancies in a casting, whether partial or thorough, which they are intended to form; allowance must also be made on them for the core prints when they are necessary. This allowance then is provided in the cores for the column sockets, for which there are prints on the under side of the pattern. These sockets go through the bed, and are square in the body and round at each end, Figs. 1289 and 1290, and Fig. 1292, which is a plan of the moulding, showing the cores in their places. Fig. 1293 is a longitudinal section, taken through the steam-ways. In both figures *f f f* is the sand of the floor, in which the moulding is formed, constituting the interior as well as the exterior of it; *b b* are the cores of the column sockets, seen in dotted lines in the section; *c*, *d* are the cores for the steam-ways which in Fig. 1293 are seen projecting in the sand, and below filling the recesses made for them by the prints. Figs. 1286 to 1288 explain the shape of them. They are formed in boxes, which open in two for the purpose of extracting them. These, with all the other small cores, are dried upon hot plates, heated by stoves. At *a* and *e c*, the cores are shown, forming the spaces in the moulding intended to be vacant. Near the under side of each, in Fig. 1293, are the plates, indicated by dark lines, which sustain the cores. The whole, however, must be sustained by the bottom of the moulding, leaving a space of required thickness of the casting. This is effected by placing chaplets there; these are simply strips of sheet iron of small lengths but with double knees, thus [. If the depth of these be just the thickness of the metal, then by placing several of them along the bed of the moulding, they support the cores placed over them, keeping the space clear for the metal; these chaplets will be imbedded in the casting, where they are allowed to remain. The double-knee cores at both ends of the moulding, Fig. 1292, are put together, each in three pieces. In constructing the cores *e e*, plain square bodies of sand, of the dimensions of the interior of the casting, are in the first place formed in boxes of the same size, including at the same time iron frames enveloped in the cores. The small cores that are necessary to the oblong openings in the sides of the casting, are simply attached in their proper positions to the sides of the main cores *e e*. They are formed and fixed by applying upon the larger core an open box of the form required, into which the sand is packed, thus causing it to adhere to the main core; when the box is filled, the sand is squared off by a straight edge flush with the surface of it. All the other smaller cores having been made and set in their places, the moulding is finally closed, the upper box being replaced, as seen in section *i i*.

When convenient, two or more gates are connected to one central reservoir, all built on the surface of the sand. Gates at considerable distances from others are usually supplied separately with iron from hand ladles. The other gates that are connected are supplied by crane ladles, which are conveyed by cranes from the cupola to the moulding. The flow gates, while the metal is being poured, are plugged with clay balls, to keep down the air in the moulding. These plugs are drawn out when the moulding is filled and the iron flows up. It is thus judged whether the casting is complete.

When the metal is poured, the feeders are immediately applied at the flow gates. These are rods of iron which are plunged into the liquid iron, and wrought up and down in it. By this agitative process, the liquidity of the iron about the gates is of longer duration than otherwise maintained. It is therefore enabled to supply itself with additional iron from the flow gates.

Amongst the great variety of work denominated green-sand moulding, much and varied contrivance is displayed in the structure of the moulds. In particular, the management of cores is a matter of very considerable importance, and the malformation of them is a prolific source of failure in the production of sound castings.

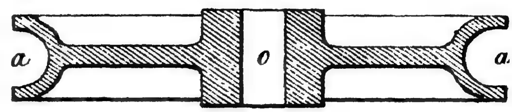
At Woolwich a modified form of plate moulding was much used in casting the spherical shot and shell, in the following manner;—

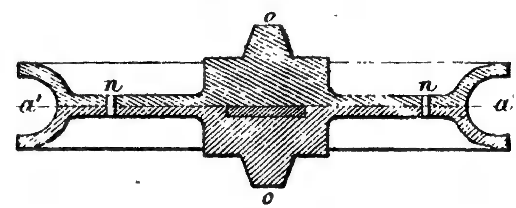
A round hole is made in a flat planed plate of iron about 2 in. in thickness. A solid ball is passed through this aperture, of corresponding diameter with the hole, until exactly a half of it can be seen. The lower flask is then put on to the plate, and the sand rammed in; a lever is then taken away, and the ball at once falls by its own weight; the lower flask is removed, and the upper put on the plate. The same operation is gone through with this also.

The cores for filling up the centre of shell are very correctly made, and in very little time, at Woolwich. A lever opens and shuts the halves of the core mould, so that the plan sometimes resorted to of shaking and knocking the core mould is entirely done away with.

Shells of the modern form are moulded in a somewhat similar way, but in a flask resembling Fig. 1274, care being taken to get good sound metal by pouring in the iron while liquid into small hand ladles, each of which has arranged over it a receptacle into which all scum rises; when required, the filled ladles are removed from under these receptacles, and the clean metal poured from them into the moulds, the metal from the receptacles, amounting to at least 25 per cent. of that employed, being returned to the cupola.

1294.





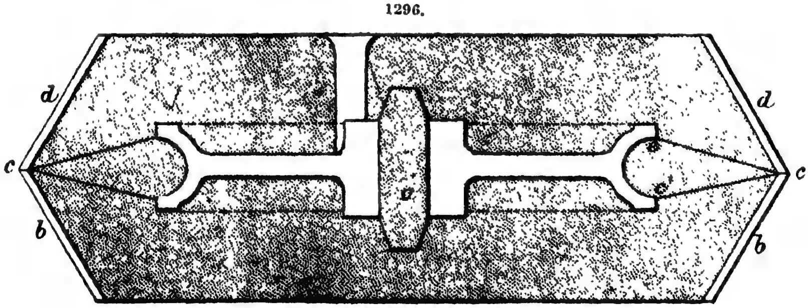
1295.

Figs. 1294 to 1297 illustrate the moulding of a common sheave, and also a manner of constructing patterns, when certain portions of a pattern enveloped in the sand, project horizontally beyond other parts which are above them. The circumference, it will be observed, is grooved out semicircularly at *a*, and a hole *o* is made through the centre. The object is now, to mould the pattern in such a manner as that the portion of sand forming the groove *a a*, may be left in its place when the pattern is drawn out. The pattern, Fig. 1295, must be formed in two halves, separated by the plane *a'* passing to the centre of the groove. These halves are prevented from shifting by pins *n n*, or this may also be effected by a button on the centre of the one, fitting a recess in the other, as in the figure. There are also prints at *o o*, for supporting the core.

Fig. 1296 represents, in section, the moulding of the pulley, *d d* and *b b* are the boxes. The pattern is first bedded in the lower box, and a parting *c c'* formed from the under rim to the edge of the box. The ring of sand *c c' e* is, in the next place, rammed about the pattern, filling the groove, and its upper parting surface *c c* is brought from the upper rim. Again, the upper box is placed on the other, and also filled.

The ramming being now completed, and the gate pin set, the box *d d* is lifted off, carrying with it the impression of the upper side of the pattern. The upper half of the pattern being free, is

1296.



lifted away, and the box *d d* replaced. The whole is now inverted, and the box *b b* is lifted off, thus permitting the remaining part of the pattern to be removed, which being done, and the moulding blackened and smoothed, and the core *o* set in, the box is replaced, and the two are finally reinverted. The annular core *c d e* is never lifted from its situation during the process, and when the two boxes are linked together, it is wedged in on every side, and thus all possibility of shifting is removed.

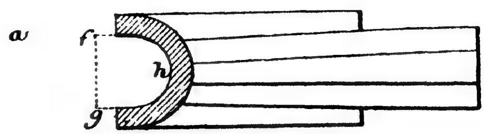
When there may not be facilities for turning the patterns of pulleys of large diameter, the grooves are cored out in the moulding. For this purpose a core print running round the pattern is provided in the making, as in Fig. 1297, which is a section of a rim of a wheel supposed to be made with arms. The print is indicated by the dotted lines, and a core of the sectional form *f g h* is constructed in a core box for the purpose. As there are only two boxes for the moulding, the pattern is mostly imbedded in the under one, the parting being formed on a level with the core print at *f*.

It is not necessary that the core be all one piece; it may, for convenience, be formed in several segments.

A fluted pipe is another example. The core or interior of the pipe follows in form the exterior surface, the object being to make the pipe as light as possible, otherwise a round core might have been substituted.

Considering a cross section of the pipe pattern, three main divisions would suffice for a pattern having a plain exterior. If the flutes are deep, subdivisions are necessary to render the moulding of it practicable. For the angles immediately adjoining the parting overhang, and therefore if the patterns were drawn vertically out of the sand, they must break away the intervening portions of sand. Such parts of the pattern require to be removed laterally, and for this purpose, each half is made in three divisions, dovetailed to one another, allowing the smaller pieces to slide off the larger. The core box is, like the pattern, parted in two. On the top of the upper half a loose piece, the length of the box, is provided, which being removed, the sand for the core may be introduced by the opening.

1297.



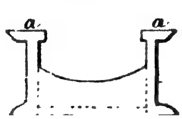
The pattern having been moulded in the usual manner, one-half in each box, the middle piece of each half is first drawn out, when the smaller pieces may next be removed laterally to make way for the core.

On this principle of construction, in similar circumstances, patterns are generally made. Fitting strips, for example, when applied to the vertical face of a pattern, below the surface of the moulding, are attached to it by sliding dovetails. Core prints are very often placed in such circumstances, and, instead of being dovetailed to the pattern, are carried quite down to the plate, which is moulded in an inverted position; these continuations clear the way for the prints themselves, as the latter would otherwise break the moulding. After the cores are introduced, these temporary vacancies are filled up with the aid of smooth strips of wood, and the figure of the moulding restored. In general, core prints on vertical faces of patterns, are carried up to the parting surface, with the view of making their own passage, which is afterwards closed over the core.

A panelled octagon column or post presents a more complicated structure than the fluted pipe, and to render it workable in the sand, the panels are, each by itself, made separable from the body of the pattern, being attached to it by screw nails which are driven from the inside. The pattern is divided into two principal halves. When it is moulded, the panels, of which there are four to each half, are fixed on. When the parts of the box are separated, exposing each a half interior of the pattern, the screws are returned and withdrawn, thus leaving the frame of the pattern at liberty from the panels. It is next lifted out, and these being disengaged from the sand by tapping, are likewise taken out in order. In this way, a complete external moulding of the column is formed. The core, constructed upon a stout bar, is next inserted, and the box closed upon it.

Of the use of plates in moulding, an example has already been given in Figs. 1284 to 1293. A different application will now be described in relation to the moulding of a lathe bed. Fig. 1298 is an end view of the bed; *a a* are the upper sliding surfaces overhanging the sides; these are connected and stiffened at several parts by deep flanges joining them. The surfaces *a a*, as they are the most important parts of the bed, are, according to the general rule, moulded undermost.

1298.



1299.

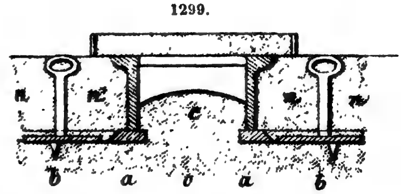


Fig. 1299 is a section of the pattern and moulding. The parts *a a* are attached by loose pins to the rest of the pattern. The first step is to bed the pattern, in an inverted position, thoroughly on the floor, which is levelled and smoothed all about it. Plates *b b*, extending the whole length of the pattern, are set along both sides of it, an inch or so apart, to support the sand exterior to the pattern. A series of small rods, either of wood or iron, are placed on each plate. These rods overhang it on the side next the pattern, from which, however, they must be at some distance. In this way the rods form a projecting platform, by which the sand that would overhang the plate is sustained. If of wood, the rods are dipped in clay water, that they may adhere to the sand. The moulding is made up with sand, flush with the pattern within and without. The parting is formed and covered in by the upper box as usual, which being lifted off, and the pattern having been loosened, it is drawn out, leaving the loose pieces *a a* imbedded in the three masses of sand *n n o*. The masses *n n*, resting on the plates, are raised and moved aside by handles which are cast upon the plates and project upwards. The pieces *a a* being thus relieved, are edged out from below the sand *o*, and removed; *n n* are replaced as before, guided by conical projections from the plates, and the moulding is covered by the upper box.

Plates are also employed in the moulds of bevel-wheel patterns, for lifting the bodies of sand sunk between the arms. Frequently, too, in miscellaneous cases, where considerable depths of

sand occur in the upper part of the mould, slips of wood are planted vertically in the masses, reaching upwards between the ribs of the upper box, their object being to bind the whole body of sand the more firmly together.

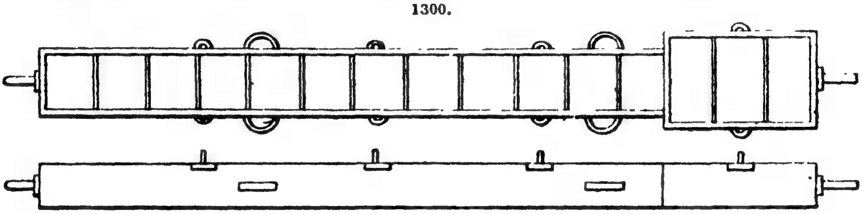
Dry-sand moulding embraces, generally, the manufacture of pipes, columns, shafts, and other long bodies of a cylindrical form, or approaching to it; the first is most important, for cast-iron pipes are extensively used to convey water, gas, or air for various technical purposes. Dry sand acquires a very firm and open consistence by the expulsion of its humidity by heat, and it is found to be much better adapted to the purposes above-mentioned than green sand.

The mechanical part of the process of moulding in dry sand is the same as in the case of green-sand work. In general, no coal powder is mixed. When the mouldings are finished, they are transferred to drying stoves, in which they are exposed twelve hours or upwards, as occasion requires, to the action of a strong heat till their humidity is banished.

When the castings are large, and especially if they are tall, the hydrostatic pressure of the metal upon the sides of the mould is counteracted, both by firmness of the sand and by the wedge-shape form of the boxes. To aid the resistance, the sides are feathered along the outside, affording additional abutting surface for the sand.

Fig. 1300 is a side view of one-half of a moulding box for pipes, the other half, Fig. 1301, being an exact counterpart. In cross section it has parallel sides, except for heavy castings, when a wedge-shaped box is employed. It is formed with flanges along the sides, which meet those of

1300.



1301.

the other box. By means of these flanges the two halves are bound together by glands. A pair of swivels is attached to the ends of each box, by which they are raised and inverted as occasion requires. Another pair is usually fixed on the middle of the sides, upon which, when the boxes are hung, they may turn in a direction perpendicular to the preceding, that they may be set vertically at their destined position, which is commonly in a pit dug to receive them.

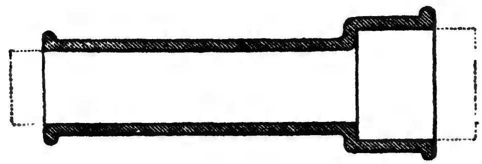
Pipe moulds are always either set upright on one end, or laid in a position very considerably inclined, on a bed of sand prepared for the boxes at an angle of 30° or 40°. When practicable, the larger sizes of pipe moulds are placed in a vertical position, as well as all other comparatively tall articles; the general object being to raise all the slag that collects on the surface of the iron, while being poured, clear of the cast into the gate-way, securing thereby soundness to the cast.

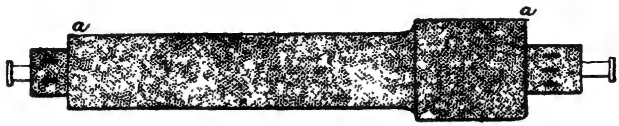
In the constructing of pipe moulds, as well as the moulds of all other large hollow articles, it is necessary that the core be made both rigid and porous. Both of these objects are accomplished by employing a tube of iron, forming the centre of the core, and perforated at regular distances for the escape of the air. For the smallest sizes of cores, common gas-pipes are used, with holes drilled in them at about 9 in. distance, on alternate sides. Wrought-iron tubes of a larger size are employed for larger pipes; and for the largest sizes cast-iron pipes are adopted, with rows of oblong holes cut at equal distances for ventilation. These cast-iron core bars, the general appellation for all the varieties enumerated, have wrought-iron double knees, fitted and bolted to their extremities, for the purpose of sustaining journals or bearings, upon which they may be turned on their own axes. The hollow ends of the wrought-iron pipes are formed square to receive a winch, by which they also may be made to turn upon themselves.

Again, a core bar for a pipe of any given inside diameter is selected 2 or 3 in. less in diameter, with the view of providing for hay-rope and loam, by which the core is made up to the necessary thickness. The loam, which forms the external coat of the core, is made as open as practicable by augmenting the usual proportion of sharp sand in its composition. The hay, also, which is simply twisted into ropes to facilitate its application to the core, fulfils the important office of a conducting medium for the air forced through the loam, leading it from all parts of the surface to the vent-holes in the core bar. The method of applying the hay and the loam is simple. The core bar is rested by its pivots on two iron tresses, the upper edges of which are formed with corresponding semicircular or triangular bearings, to receive the pivots. Thus placed, the core bar is caused to revolve by a crank handle applied at one extremity, during which operation the rope is led on regularly along the bar from end to end, and fastened there. It must be tightly done, as any slackness in the rope will permit it to yield when subjected to the pressure of the iron, which has the effect, at least, of altering the form of the pipe, if, as in some cases, it does not break up the core and spoil the casting. Before finishing the core with loam, the hay receives a slight coating of it all over, as a cement to smooth down the surface. This being dried, for the succeeding application of the loam, a loam board is necessary. This is a board of sufficient length to rest upon the tresses which support the core. Along this board is laid the loam intended to form the core. The edge of the board is cut exactly to the form of the core, being indeed a half skeleton reversed. This board being set alongside the bar, and weighted down at the extremities, at a distance of the half diameter of the pipe from the centre, it is evident that, as the core bar revolves and the loam is pushed over upon it, there will ultimately be formed a coating of loam completely enveloping the coat of hay, which shall also possess the figure of the core.

In this manner the core is formed. Figs. 1302 to 1310 illustrate the process. Fig. 1302 is a longitudinal section of a pipe, in which the exterior and interior outlines are represented. The dotted lines at each end indicate the additions necessary in the pattern as core prints. Fig. 1303 represents the core as formed upon the bar, the core being prolonged to be supported in its bearings formed by the pattern, though it matters not if it should be longer than necessary. Fig. 1306 repre-

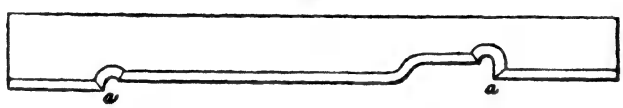
1302.





sents the core bar with its pivots at the ends, and the vent holes scattered over its surface. Fig. 1305 shows the loam board employed in constructing the core of the pipe. It will be observed to follow the outline of the core. Fig. 1304, in like manner, represents the loam board that would be required to form the pipe itself, Fig. 1302, were there no wood pattern of it. In such a case an additional coat of loam is run by means of it upon the core. In setting the board, the parts *a a*, Fig. 1304, will apply to the same parts *a a*, Fig. 1303, which, in so far, serve for a gauge. The misplacing of them is to be guarded against, as there is not the same security for their being correctly placed. Before receiving, however, the additional thickness, the core must be washed

1304.



over the surface with charcoal and water, that the thickness may be easily separable afterwards, and also thoroughly dried in the stove. In the meantime, having finished and dried the loam pattern, it receives in like manner a wash with charcoal water, and is ready to be moulded. This being done in the usual manner, the thickness is peeled off, and the naked core replaced in the mould. To aid the stiffness of the core, steeples or moulders' nails are planted here and there over the surface of the mould, which resist any undue tendency of the core on one side or another. Fig. 1307 is a cross section of the body of the core. There are three concentric plies, the inmost,

1305.

1306.

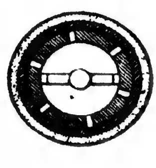
which is the core bar, with several vent holes in section, and the cross-knee at the end; the next the hay, and the external coat is the loam. Fig. 1309 is a sketch of one of the iron tresses used in the work.

All wood patterns of pipes are constructed in two halves, which have two or more pins in the one, entering corresponding recesses in the other, to prevent their shifting when put together and moulded. In proceeding to mould a pipe, a laying-down board is usually employed, which is simply a straight piece of wood as long and as wide as the moulding box. Upon this board one half of the pipe is laid with the flat side down, the box is placed over it, and rammed; the whole is inverted and the board lifted off. The remaining half of the pipe is set upon the imbedded half, and the upper box over it, and linked to the under one; the upper box being rammed, the patterns are loosened, as we have elsewhere described, and longitudinally also by blows upon the ends. The boxes being parted, the patterns removed, and the moulding blackwashed with blackening, the core is set in and the box closed. Small pipes, when there are several to be cast, are usually moulded in pairs in one box, when green sand is employed as a moulding material. The

metal is poured in at one entrance, which branches to each moulding; shortly after which streams of aqueous vapour mixed with hydrogen and other gases, arising from the imperfect combustion of the charcoal and hay, are expelled from the extremities of the core bars, sometimes resolving themselves into luminous jets. Soon after the metal is poured, the castings are turned out to cool; after which the core bars are drawn from them, which is a comparatively easy task, as the hay has been for the most part consumed, and of course occupies less bulk. Long narrow rods of iron are next introduced, with scrapers formed on the ends of them, and they are drawn from end to end to clear the interior of the pipe of the remains of the core.

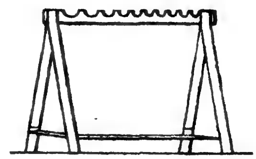
In the moulding of the various lengths of pipe that are required for use, one pattern is made to answer. Pipe patterns are generally made 9 ft. long, of which an appropriate number of lengths are cast when more than 9 ft. of piping is required. But shorter lengths also are frequently wanted, when, of course, the full length of the pattern would not be proper. The moulding therefore is cut

1307.



1308.

1309.



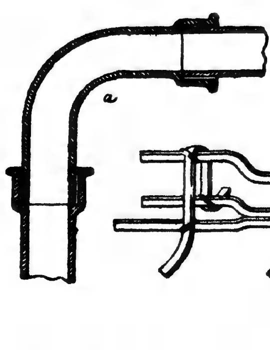
1310.

to the required length; in technical language, the pattern is cut in the sand. In such a case some preparation is necessary to form a new bearing for the core. For this purpose, two semicircular pieces of wood, of the diameters of the mould and the core respectively, are sprigged together end to end, as in Fig. 1308; and by placing the larger piece in the mould in each box at corresponding parts, and ramming fresh sand about the former, the bearing will be formed. In like manner, if the piece of pipe terminate in a flange, the flange having been moulded in its place, a half flange of the same dimensions, with a half core-print on it, as at Fig. 1310, is set into the mould, and the bearings for the core made up. Small perpendicular branches required to be made upon pipes are cast either horizontally or vertically, as best may suit the form of the box. In the latter case, the branch pattern is set loose upon the pipe, projecting upwards between the ribs of the box, and, having been moulded, it is drawn out, and its core set in upon the pipe core, and the whole covered in.

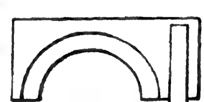
In arrangements of pipe works there is usually a number of knees or bends in their construction. These bends are ordinarily cast separate from the straight portions of pipe, having facets upon them by which they may be afterwards joined to the pipes. Fig. 1311 is a longitudinal section of a square knee in a line of pipes, showing the method of junction by spigot and facet. The term spigot, it may be as well to observe, is applied to the small semicircular ring upon the plain end of a pipe, as may be seen in Fig. 1302; facet denominates the cup mouth on the other end for receiving the spigot. There are usually patterns and core boxes for pipe bends of the usual square knee shape, in which case they are moulded in green sand. In the absence of patterns, however, for these and for other varieties of short piping, they are swept up in loam, the core within the thickness.

In this process, the first point is to have a level iron plate set, upon which the work is to be done. Like patterns, the loam work is to be formed in two halves. The cores are executed in the first place, and, when dried, the thicknesses forming the exterior of the casting are next laid

1311.



1312.



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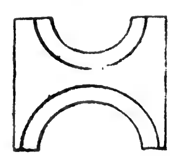
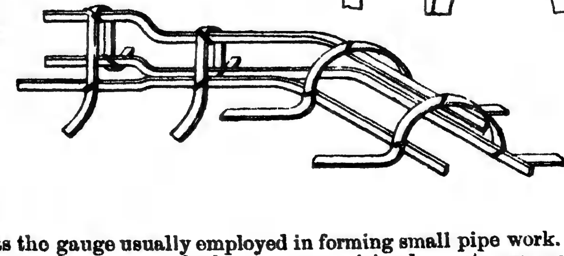




on. Fig. 1313 represents the gauge usually employed in forming small pipe work. As already said, the work is done in separate halves, for which purpose semicircular cuts are made in the gauge, of which one is smaller than the other, being respectively the measures of the core, and of the additional thickness.

For example, suppose a bend, Fig. 1311, is to be constructed, a small square rod of iron is bent to the form of the knee, against and along the side of which the gauge is moved. A quantity of loam

being laid on the plate in the line of the pipe to be formed, the gauge in its progress fashioning the loam to its own form. When the two half cores are in this manner swept up, they are well dried and blackwashed, after which the gauge is inverted, and additional loam being laid on for thickness, it is likewise shaped to the form of the pipe. The junction of the body of the pipe and facet, which are of different diameters, and of course require different sweeps, is scraped out by a file when the loam is dried; the head on the end of the facet is either formed by a pattern applied to the moulding, or cut out of the cope.

The loam pattern being thus completed in two halves, dried and blackened, it is bound together at two or three places by iron wire, and bedded half into a sufficient quantity of old loam mixed with water and laid over the iron plate. The boundary of the loam is built up with fragments of cake loam. The bed being smoothed off on each side and dried, a layer of the same watered loam is applied to cover in the upper half of the pattern. As this upper layer has afterwards to be lifted whole, it requires to be strengthened by the addition of irons. With this view, pieces of rod iron, accommodated to the form of the moulding, are laid on among the wet loam transversely and longitudinally, and bound together by wires at the angles, constituting a kind of skeleton framework, Fig. 1314, for the cope, as it is termed, or upper structure. The irons are then covered in with old loam, which is smoothed over them, and the whole is for the last time thoroughly dried.

The building of the work being now completed, the next step is to undo it to clear out the thickness. The cope is lifted off carefully, leaving the rest of the work behind it, and this complete separation of the parts is one object for which the blackening and charcoal water is applied. In the same way the pattern is lifted out from the bed of the moulding. The thickness is easily broken off the core, leaving the latter entire; the halves of which are next bound by wire, and replaced in the mould, stayed by bearings at the ends, and by steeples intermediately. The cope is replaced, guided to its former situation by intentional irregularities on the junction surface, and is bound by wires laying hold of the skeleton, to the under plate. The gate is formed in the usual manner by a pin stuck in the cope while being formed.

For some small pipes, such as bends, which are uniformly circular, circular iron plates are frequently made to the same centre on both sides, so that when the cores are swept up on them, they lie concentric with each other. The edges of the plate will therefore serve for guides in the making of the core. For this purpose the gauges are made as in Fig. 1312, having a piece of wood nailed on and projecting downwards. By sliding this gauge along the interior or exterior edge, as it may be adapted for them, the pipe is formed as before. The manner of moulding and casting columns of every variety, and other long hollow work, is essentially the same as that now described for pipes.

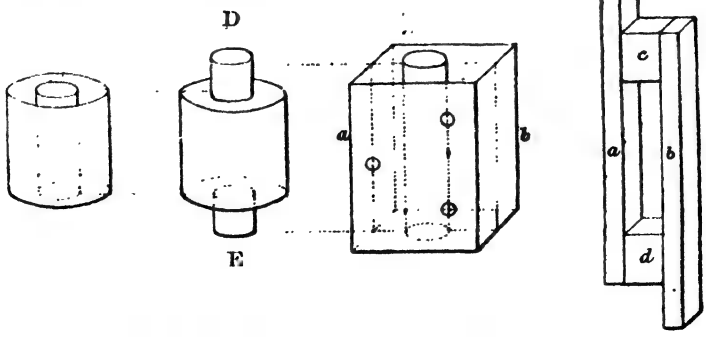
Cast iron, bronze, or steel guns are moulded in the way just described. Patterns of wood are not often employed, as it is worth while to construct iron patterns, which, when turned and polished in the lathe, always preserve their figure and turn out good moulds.

As it is desirable to have these iron patterns as light as possible, consistent with the straining to which they may be subjected, they are made hollow throughout. It is then the business of the moulder, in the first place, to form a hay-and-loam pattern in a manner similar to that in which pipe patterns of loam are made.

As it is of great importance to secure solidity to gun-castings, they are made without bore, and with an additional length on the muzzle end, which is provided for in the pattern. When the mould is formed and set on end in readiness for being cast, the metal is poured into it, slowly at first, increasing in flow as the mould is filled to the top, which is left open. Into this additional portion, then, all the sullage rises that is collected during the course of the pouring, leaving the body of the gun-casting generally in a pure state. The moulding sand adheres very firmly to the casting, and requires to be knocked off by hammer and chisel afterwards in the course of dressing.

Guns were formerly nearly all cast, and their manufacture formed a large feature in the moulding business; the introduction of built-up wrought-iron guns has, however, changed all this, and ordnance is not cast as it used to be.

1315. 1316. 1317. 1318.



Figs. 1315 to 1318 illustrate the use of cores and core prints. Fig. 1315 is supposed to be a coupling for shafting of a cylindrical form, 12 in. deep by 8 in. diameter outside and 4 in. inside. A pattern, Fig. 1316, of the same size is constructed, and two prints, D and E, are put on in the

proper positions to support the core; this is made of sand in a box, Fig. 1317, which is simply two thick pieces of wood, *a* and *b*, held together by wooden pins. Square cores are formed by two slips of wood, *a* and *b*, Fig. 1318, of the required thickness, and kept apart at the ends by two pieces, *c d*, forming, by filling the spaces within with sand, the core required, thus, by means of distinct cores formed by boxes, holes and recesses of every kind are made in castings, if they are not already formed in the pattern.

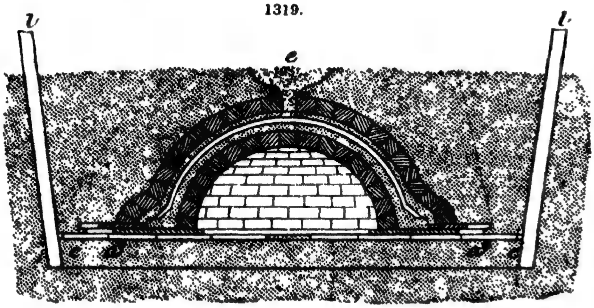
Every piece of loam moulding, of any considerable extent, is a regularly built structure, being composed of bricks, arranged in layers, and bedded in loam, in which they are also entirely enveloped, particularly on those sides contiguous to the mould.

For all varieties of circular bodies, or such as may be described round one axis, a wooden board is cut on one edge to the exact form of the object, being, in fact, a half skeleton of its outline. If the body be cored out, a board must also be provided, cut to the form of the interior space. A central spindle is erected, which is to represent the centre of the body to be moulded; to this spindle one or more arms are screwed, provided with glands, by which the loam board, as it is termed, is set at the proper radial distance from the centre, and firmly fixed to it.

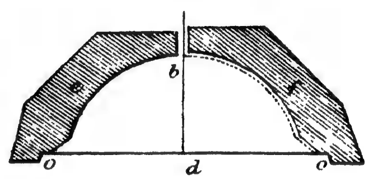
Large iron pans used in soda, sugar, and other chemical manufactures, are amongst the most familiar examples of loam moulding, and instructive specimens of this kind of work.

Fig. 1319 is a general view of a mould for a common-shaped sugar pan. The pan is moulded and cast in an inverted position, similar to the Irish pots already described. A cast-iron ring *a' a'*, Fig. 1323, is levelled upon blocks, which raise it off the floor of the foundry, and is placed concentric with a spindle *b'*, which stands upright, being placed at the under end in a cast-iron step sunk in the floor, and stayed at the upper end in a bush on the end of a bracket *c'*, which

1319.



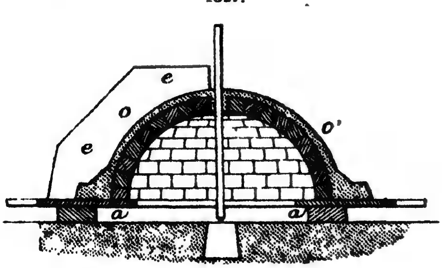
1320.



projects from the wall, and turns horizontally upon pivots. The spindle thus stayed is free to move round in both directions. To prevent the bracket from moving on its pivots, it is linked by the extremity to the wall. A forked arm *d* is fixed upon the spindle by an eye at one end, tightened by a pinching screw. Between the branches of this arm the loam board *e* is set, and fixed by glands in the required position.

Fig. 1320 represents the outlines to which loam boards are cut; *o b o* is the figure of the interior surface of the pan, *b d* being the axis. A board *e* is, in the first place, cut to the semi-outline of the interior; and further, has an additional check *o*, which turns out a corresponding knee in the mould, the object of which is to support the overlying part of the mould on its horizontal surface, and to act afterwards, by its vertical surface, as a guide in replacing the mould. Another board *f*, is in the same way cut to the external figure of the pan, with a check precisely similar to the one in the board *e*, and thus it will act as a guide in setting the second board.

1321.



1322.

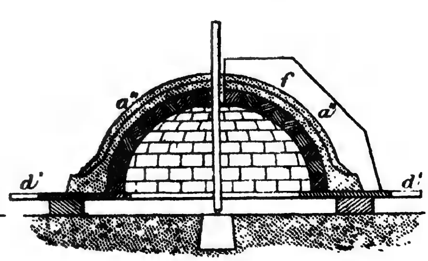
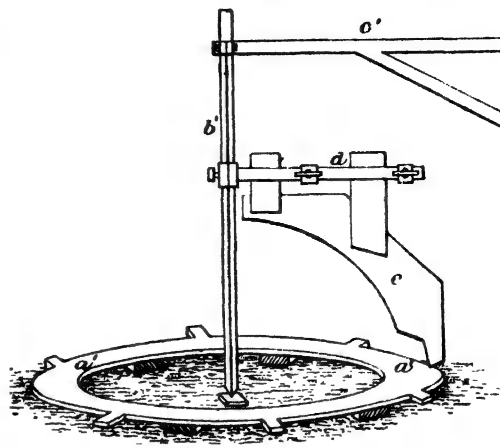


Fig. 1321 is a vertical section of the work in the first stage of its progress. Upon the ring *a a* a kind of dome is, in the first place, built of bricks and loam, generally some 4 in. thick. The moulder is guided in the construction of this dome by the interior loam board, sustained by the spindle. The external surface ought to be everywhere about 2 in. distant from the surface described by the board *e e*. Before building up the dome to the crown, coals are placed in the floor within it, which are afterwards kindled for drying the work. The crown is then nearly completed, leaving only a small space round the spindle, to allow of ventilation when the combustion is going on. By this aperture the moulder is enabled to manage his fire, so as to check its progress, if neces-

sary. The consumption ought to be very slow, so as to allow of the heat taking effect upon the entire mass.

Over the brick dome a pasty layer of core loam $o' o'$ is applied; for it is in fact the core that is now being formed. The surface is finished off by a smoothing coating of wet loam, the redundancies all over the surface being swept off by the board in its revolution. Upon this surface the inside of the pan is cast. The fire is now kindled, and as the surface of the mould becomes dry, it is painted over by a brush with a mixture of water and charcoal powder, with a little clay additional. This operation prevents adhesion between the surfaces of the core and the coat of loam applied to it.

1323.



The core board having been removed, it is replaced, as in Fig. 1322, by the thickness board *f*, Fig. 1320, of which the edge describes the external surface of the pan, and, as already remarked, simply rubs against the knee formed round the base of the core. Another layer of loam $a'' a''$ is then spread over the core, and is rounded off properly by the board similarly to the core itself. When well dried it is blackwashed, as was done to the core. The upright spindle is now removed, leaving the small vent-hole through which it passed to promote the complete combustion of the coal. There is now laid horizontally upon the ears of the platform $d' d'$, Fig. 1322, another platform similar to the former, but sufficiently large to pass over the moulding already executed. A new layer of loam, 2 in. thick, is laid over the thickness and smoothed by hand. Then, upon the second platform, a brick vault is constructed as before, of which the inner surface applies to the new coat of loam. This contracts a strong adherence with the bricks, which absorb a part of its moisture, while the coat of paint prevents its adhesion to the thickness. The brick and loam covering are named the cope.

The whole mass must now be thoroughly baked by the continuance of the fire. Stoves are preferred to internal fires where they are large enough to receive the work.

Cast-iron bars may be substituted for the brick forming the cope. These irons must have the curved form of the dome to which they apply, being arranged so as to converge towards the crown. They are simply run off in open sand, when required, with snugs cast upon them, by which the cope may be lifted off. They are bedded in the external coat of loam, which is smoothed over them, and bound together by wires and bands of hoop-iron.

The next step is to lift off the cope, which is done with the assistance of a crane. This being effected, access is had to the interior, and the thickness is easily broken away without any injury to the mould; this thickness forming, in fact, the pattern of the pan, it is evident that when the cope is replaced exactly, which it may be by the guidance of the knee before described, there will be a space within to be filled with metal; this space is the true form of the pan. Before replacing the cope, the vent aperture in the core is filled up and smoothed over, though the one in the cope is left open to serve afterwards as a gate for the reception of the metal.

The cope being reset, and clamped firmly to the core by double knees and wedges, embracing the rings, the whole is removed to the pit in which it is sunk, and rammed up tightly with sand by iron rammers, which are managed by half-a-dozen or more men, who walk regularly round the moulds, keeping time with their rammers, and dealing heavy and light blows alternately, while one or two workmen above, shovel in additional sand as required. Fig. 1319 is a vertical section of the pit, showing the manner in which it is arranged. A space sufficiently deep is first cleared out, and across the bottom a passage $a^* a^*$ is cut, and overlaid with plates, having only an open part in the centre which connects it with the interior space in the mould. Two pipes $c\,l$, $c\,l$ are next laid in against the sides of the pit, communicating with the channel $a^* a^*$. When the mould is lowered into its position in the centre as indicated, and the sand rammed about it in the way already described, an oblong, shallow, trough-like cavity *e* is formed in the surface of the sand, one end of which opens into the gate hole of the mould, which is closed by a pin while the ramming is proceeded with.

The channel $a^* a^*$ and the pipes fulfil the purpose of venting the air confined in the hollow space, together with what is forced through the substance of the core, when the metal is poured. Now, as a large quantity of inflammable gas is driven off, its union with the atmospheric air in the chambers below forms a dangerous explosive mixture, which, rushing out of the openings *l l*, might be inflamed by accident, and, if not prevented, would blow up the whole work with irresistible force. To prevent such an occurrence, the vents are stopped at *l l* with plugs of straw or mill waste, or simply covered with pieces of fine wire sieve, the gas passing through these before being exposed to any accidental inflammation, security from explosion is rendered certain, as flame cannot pass through their interstices.

When the metal has been poured, and has well set, the casting is cleared out as quickly as possible, as, on account of the contraction it undergoes, it is apt to gain upon the core. Confined

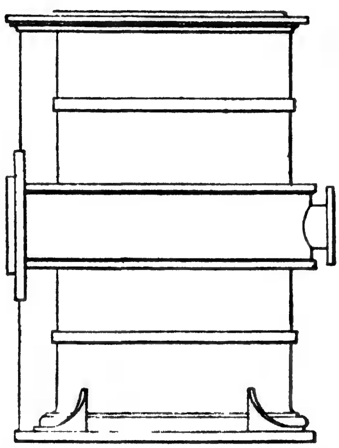
cores are always broken up as soon after casting as may be, especially when their form is calculated to resist great compressive force.

When the object to be moulded presents more complicated forms than the one now chosen for the sake of illustration, it is always by analogous processes that the workman constructs his loam moulds, but his sagacity must hit upon modes of executing many things which at first sight appear to be scarcely possible. Thus, when the forms of the interior and exterior do not permit the moulds to be separated in two pieces, it is divided into several, which are nicely fitted with adjusting pins. More than two cast-iron rings or platforms are sometimes necessary. When ovals or angular surfaces are to be traced instead of those of revolution, no upright spindle is employed, but wooden or cast-iron guides made on purpose, along which the pattern cut-out board is slid according to the drawing of the piece. In addition to brickwork, iron wires or claws are often interspersed through the work to increase its adhesion. When parts of a mould are higher than that portion immediately under the gate, flow gates are usually adapted to such parts, by which they may be relieved of the impurities that would be apt to lodge there. Such a case is that of a flattish bottomed boiler of which the bottom is hollow externally.

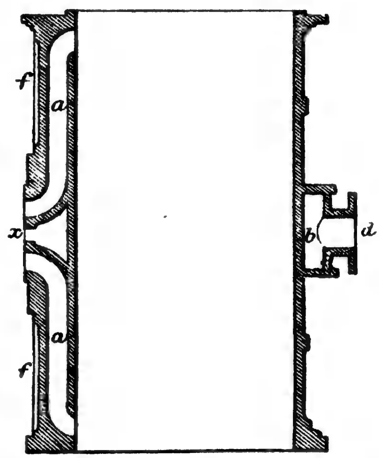
Fig. 1324 is a side elevation of a large steam cylinder; Fig. 1325 is a sectional elevation; Fig. 1326 represents a horizontal section taken through the centre of the exhaust steam passage; *a a* are the steam passages to the cylinder, *b b* the exhaust passage, all uniting in the face *x*; *d* is the outlet from the passage *b b*.

It is to be noted that the body of the cylinder is round, while the base or bottom flange *e e* is square, and the face *f x f*, containing the steam-ways, is supplementary to the main part, as also

1324.



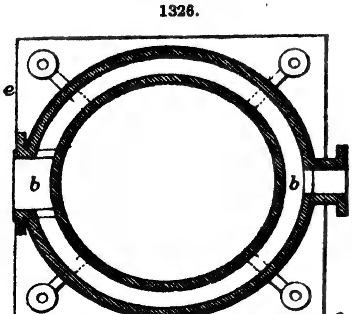
1325.



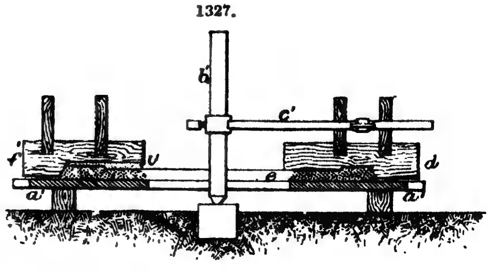
the stiffening feathers for strengthening the base. For these parts, then, patterns in wood are made adapted to fit the loam work. Figs. 1328 and 1329 are front and side views of the pattern of the part *f f*, having core prints *c c c*, for the usual purpose of steadying the cores.

As the upper flange of a cylinder, such as the one now described, is generally smaller than the under one, and more exposed to view, the cylinder is usually cast in an inverted position, to have the former flange solid. According to the method now most generally adopted for moulding

1326.



1327.



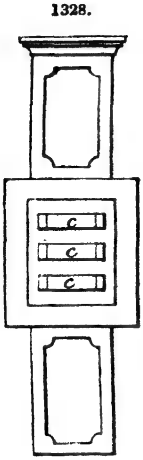
cylinders, the cope or external outline is formed in the first place by an interior loam board cut to the form on the outer edge. Thus, the cope is first constructed, after which it is removed, and on the same centre, the core or interior outline is formed by an external loam board cut on the inner edge. If the cope be replaced concentric with the core, they will include between them a vacant space, being the exact figure of the cylinder. Fig. 1327 represents the two first stages of the work;

the core ring $a' a'$, seen in section, being of the dimensions necessary for the work, is first laid down concentric with the spindle b', and levelled off the ground upon blocks. To the arm c', projecting from the spindle, the loam board d is fixed by glands embracing two arms nailed upon it. This board is cut to form the bearing e of brick and loam for the core, the bearing acting also by its sloping edge as a guard in closing the mould.

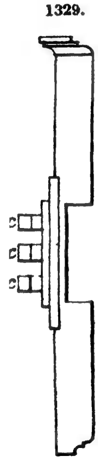
Its upper surface now forms the lower side of the cylinder flange. The board is then altered as shown at f' on the opposite side, so as to form the flange i, which is made simply of loam. This is the second stage of the work, and the flange must be dried like the bearing before it, to prepare for the next stage. It is necessary to form the flange singly, to be an additional bearing upon which the superstructure is founded. If it were cut at once out of the cope, the overhanging loam must give way.

The arm c' is now shifted up along the spindle sufficiently high for the next operation represented at Fig. 1330. A loam board d is cut to the form of that part of the cylinder included between the extreme flanges, these, themselves, as we have stated, being made of loam and wood. The board

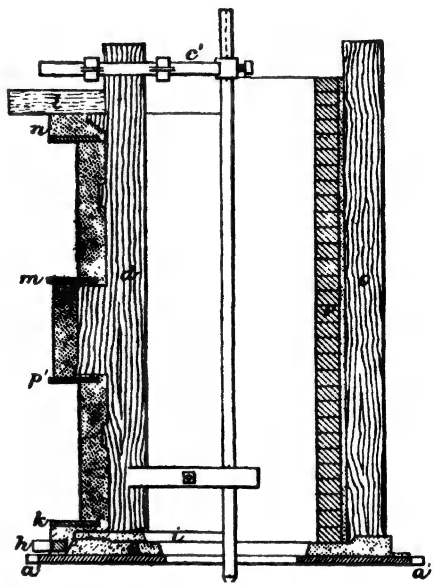
1328.



1329.



1330.



includes the exterior outline of the circular exhaust passage; and, when set in motion, it touches the flange at the bottom, and a horizontal piece l projects from it to the top, to sweep a flat surface on the cope, upon which the square flange is to be laid. The arm c' is assisted in holding the board by two pieces of iron at the bottom, screwed together upon the spindle and the board, the cope ring h having been laid down upon the core ring $a' a'$, surrounding the bearing e, with a little space between them. The steam-way pattern, Figs. 1328 and 1329, is set in its place in an inverted position resting on the flange i. Its precise position will be ascertained by the loam board, which ought to touch it when it passes round. The building is commenced upon the cope ring; and having been raised upon the flange i, another ring k is bedded on the building, lying near into the loam board, with a segment cut out of it sufficient to clear the steam-way patterns on both sides. Upon this ring the building is continued till near the under side of the exhaust passage; at which place a similar ring p' is bedded on the structure, overhanging it sufficiently to sustain the building round the passage, at which place it is greater in diameter. Having built up the height of the passage indicated by the board, a layer of loam on the top is swept flush with the upper side of the projection, by means of a stick nailed on the board. This forms a parting surface. After black-washing the surface, a third ring m, with projecting snugs on its rim, is laid over it, being faced, however, with a layer of loam to protect it from the melted iron. The building is continued upon this plate till it reaches the top, when it is succeeded by another plate n, of a square external form, and somewhat larger than the square base plate of the casting immediately over it. The building is finally carried up to the horizontal piece l, which smooths off the upper surface with loam.

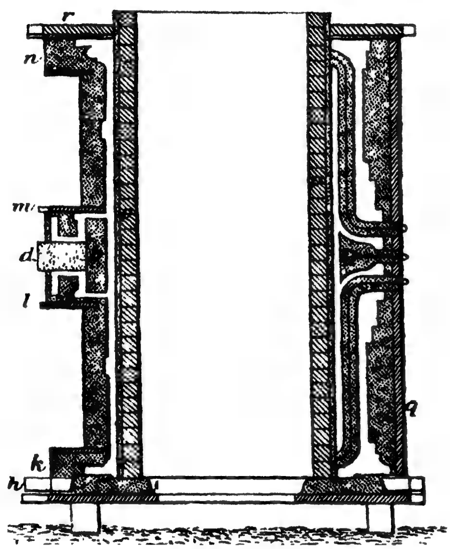
It will be remembered that the mould is, on one side, cut longitudinally throughout by the pattern of the steam-ways. On that side therefore it has to be completed; this object is attained by providing a cast-iron plate, done in open sand, fitting generally the interior of the pattern, and having three openings, through which the core prints are passed when the plate is applied. It is daubed all over the inner face with stiff loam, and being set up in its place, the loam receives the impression of the face of the pattern. Lastly, the square flange pattern is laid over the whole, upon the bed prepared for it, preceded by the four stiffening flanges, and is surrounded with additional loam, flush with its upper side, to form a bearing for the top plate.

The whole mould from the bottom is lifted by the snugs on the cope ring h, off the core ring

upon which the two layers *e* and *i* are left. It is conveyed to a sufficiently large drying stove to be thoroughly dried.

Moulding the core is an operation comparatively easy, as it is a simple cylinder of brick and loam. As the loam flange *i* has formed its impression on the interior mould under the plate *k*, it is of no further use, and is therefore broken away, leaving the bearing clean to receive the core, as the right side of Fig. 1330; *o* is the loam board in its proper position for working, having its inner edge set parallel to the spindle, and to the diameter of the cylinder required, and simply fixed to the arm at the top. A cylinder of brickwork *p* is first built up, being everywhere an inch or so clear of the board. A coat of loam is next laid on as usual, to fill up the clearance and complete the core. The board and the spindle being removed, the work is lifted away to the stove, on the core ring *a' a'*, by the snugs upon its rim.

The smaller cores, which are to form the steam passages, are for the supply passages *a a*, and the exhaust passage *b*. The two former being of the same shape, may be formed from one core box, seen in plan and section, Figs. 1334, 1335, for such kinds of cores are usually formed on three sides, and open on the fourth side to admit the material, which is shaped off on this side, by the edge of a piece of wood cut to the contour of the core, and drawn along upon the sides of the core box as



1332.

to [illegible] boxes, and fitted to the other. Fig. 1333 is a vertical view of the method of making the annular core. It is built upon a portable square table convenient for small circular work generally, as it may be conveyed to the stove without the necessity of shifting the centre. The spindle turns by a conical pivot on its under end, moving in a socket, which is the only staying it requires. A block *a'' a''* is first prepared, being a plain built ring of which the exterior is smoothed with loam, and is made exactly to the interior diameter of the core and to the same depth. The core, seen in section at *b''*, is run upon the outside of the block to the necessary thickness, in the course of which two wrought-iron angular rods are imbedded in the core to impart their thickness to it. At *b'* is shown the valve-face portion of the core, of which *x'* is the box, in section, for making it. The round core for the short, straight passage *d*, Fig. 1331, is made of loam, being run up on a short iron centre.

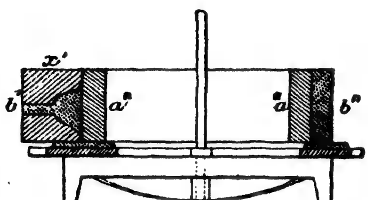
In the making of these small cores, as in those of green sand, it is necessary that they be strengthened with iron rods bent to their form, so as to pass through the heart of them, and finished with eyes at their outer extremities, for locking to the face plate. An open passage running through each core is formed, as in green-sand cores, by laying pieces of cord along the irons. These passages are of great importance, as upon them depends the escape, through the openings in the face plate, of the otherwise confined air existing in the mould, while the metal is being run. The too close proximity of these passages, at any point, to the surface of the cores must be well guarded against.

Fig. 1332 is a side view in section of the mode of placing and fixing the cores for the steam-ways to the cylinder; *q q* is the face plate lined with stiff loam, which retains the impression of the steam-way pattern; *g g* are the two cores, the nearer ends of which are passed through the openings made in the plate for them, and fixed there by small rods passed through the eyes of the stiffening irons. The ends are made with shoulders which bear upon the upper side of the plate, Fig. 1332, which may be understood from the form of the prints in Fig. 1329. The horizontal parts of the cores are supported at their proper distance off the loam work beneath them, by steeples or nails stuck into it.

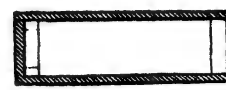
The mould and the cores having been well dried, they are dressed and smoothed where necessary, and finished with a coat of coal powder.

Fig. 1331 is a vertical section of the whole mould, showing all the parts fitted to one another, so as to contain among themselves the vacant space, indicated by a white ground, into which the metal is delivered. The main core *p p* is lowered upon its rings, from which it is never separated, into a pit dug in the floor of the foundry. The exhaust-passage core is next deposited in its exact position in its place on the top of the lower part of the cope, being sustained in the usual manner

1333.



1334.



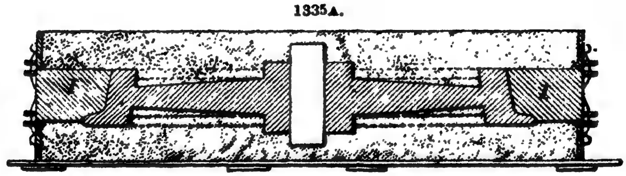
1335.

off the core by chaplets made of two pieces of strong hoop iron, riveted on the ends of two studs, so as to have the necessary thickness of space. The lower part of the cope thus furnished is next lowered over the main core, into its place upon the core ring, thus surrounding the core, and containing with it a space between, as indicated in the figure. Another set of chaplets are deposited upon the exhaust core, which, by being in contact with the upper half of the cope when placed above, prevent the core from floating off its seat when immersed in the flowing metal.

The upper part of the cope having been let down into its place, the face plate, with its cores fixed to it, Fig. 1332, is let down in front of the vacancy in the side of the cope, till it arrives at the proper height, when it is set close into its place, and the end of the exhaust core receives *b'*, through the middle opening in the plate, and is secured on the outside by the eye. The branch core *d* is then set in and supported on chaplets, and over it a ring or cake of loam *m l*, seen in section in the figure, is placed, being strengthened internally with iron, like the cores. The cake of loam forms by its inner surface the outer surface of the flange.

The mould being all finished below the top, the pit sand is rammed tightly round it, to enable it to withstand the pressure of the metal, air vents being provided in a manner similar to those for the plan already described. The top plate *r r* is laid on lastly, holes being provided in it for the admission of the metal. It is covered in with sand, through which passages are led up to form the holes to the external surface as runners or gates.

1335A.



Chill-casting and the moulds required have been treated at length in the article on Cast Iron, p. 321. Fig. 1335A illustrates the method of applying the chill to a railway wheel. The mould is here contained by three boxes, the middle box I I being a solid ring of cast iron, whose interior shapes and chills the outer part of the rim of the wheel.

Where a very large number of small articles, such as door and coffin furniture, the ornamental nails used by upholsterers, small working parts of agricultural machines, sewing machines, and the like, are required, they are almost always plate moulded. Besides its employment in the production of an infinite variety of the small ware of the hardware trade, plate moulding has certain advantages which recommend themselves to the notice of the mechani-fre

In commencing the operation, a pattern or pattern plate of the article to be d bed om is prepared, with an allowance for the thickness, placed upon a board, set upon a deep and so the b of sand. A moulding box, about 6 in. larger than the pattern every way, is then placed upon of sanoard; the pattern being set fair in the middle, it is rammed up and turned over another solid boa out o d; the board is then removed and the parting carefully made. The top part of the box is then p att n to the part already rammed up, which is the drag; the gate pins are put in suitable places, and this also is rammed up.

The two parts are then separated, and a frame of wood, about ½ in. thick and 1½ in. broad, is placed on the parting, keeping the pattern fair in the middle. The outside of the frame is made up firmly with sand, so as to resist the pressure of the metal; a piece of iron, the same thickness as the frame, 2 in. broad and about 4 in. long, is placed on each corner of the under part of the box or drag, so that when the top part is placed on it, it will be raised up the thickness of the frame.

The frame and patterns are then removed, and the mould is carefully finished. The top part is afterwards placed upon the under part of the box, and the two parts are securely fastened together; the metal is then poured into the mould, and the pattern plate is produced; this plate is formed with four cheeks on it, which are filed and faced to ensure accuracy in the moulding. The pattern plate being cast in the manner above described, it is cleaned up and fitted to the moulding boxes, the pins and snugs of which and checks in the plate being all fitted exactly to one another. The pattern plate may be used singly, that is, it may be turned over with the top part and drag of the moulding box, or two plates may be made, the face impression being taken off one plate, and the back impression off a different plate. When two plates are used, each plate must be accurately fitted and secured to a frame, which may be constructed of wood or iron, and furnished with guides, corresponding with the pins and snugs of the moulding boxes. The pins of the moulding boxes may be either simply faced, or steel fitting straps can be inserted into grooves formed in them by mandrils.

Another method of preparing what we may term the working plates, when the moulding plate is to be made by casting the patterns upon the face or faces of a plate, is to take a copper or other metallic plate, the surface of which has been tinned, and mould, in an ordinary sand mould, the half patterns of the articles to be cast. The tinned plate being placed in the mould box with the half mould upon it, fused tin, or an alloy of tin and lead, is run into the mould. There is thereby produced a moulding plate having on one face the half patterns of the articles to be cast, together with the necessary gates, the cast patterns and gates adhering firmly to the tinned surface of the plate. Half patterns on opposite sides of the plate may be cast simultaneously in a similar way. Or instead of casting the half pattern simultaneously on opposite sides of the plate, the half patterns cast on one side of the plate, may be used for moulding the half patterns to be cast on the opposite side of the plate. By this means, great accuracy in the positions of the half patterns on opposite sides of the plate is obtained. This ingenious method was introduced by Chamberlain and Smith.

The half patterns cast upon one or on opposite sides of the plate may be made of iron instead of tin. In this case, an uncoated iron plate is used, and on this half patterns and gates are cast. After the casting process, the plate, with the slightly attached castings upon it, is plunged for a short time in a bath of melted tin, the whole becomes coated with tin, and the other patterns are firmly attached to the plate.

1335B.

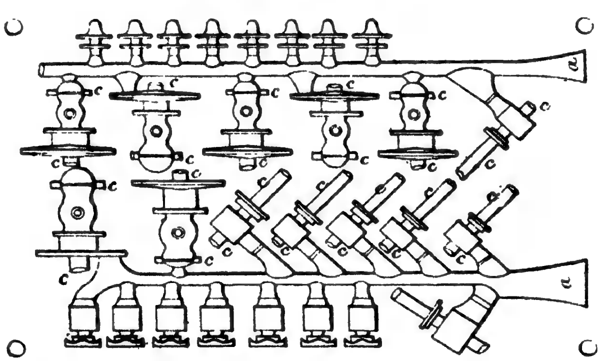


Fig. 1335B represents a plan of a moulding plate. The pattern plate is here made with a number of half patterns on opposite sides, for moulding a series of gas fittings. The gates of the half patterns are marked *a*, and the core prints of those articles which are to be cored *c c*. Holes are made at the corners of the plate.

For some articles, such as brass nails, plates with holes in them, for the pattern to go through, and also pulled out by means of leverage, are much in vogue.

The expense incurred in the first place in patterns for plate moulding is rather large, but so much can be done by the plates, of which many duplicates can be in use at the same time, that it has come into very general use.

The mode of producing moulds by employing a plate having a passage through it exactly fitting the pattern, has long been practised. The plate is arranged on a table, and covered by a box; sand is rammed around the pattern, which at that time is caused to project up above the surface of the plate, and the pattern is subsequently withdrawn, through the hole or passage. In many cases the preparation of the plate, just described, is expensive, particularly when small cog-wheels are moulded in this manner, as the holes in the plate should fit accurately over the pattern. To remedy this, Jobson and Ransome introduced a plan, by which the opening on the plate is formed somewhat larger than is required for the passage of the pattern, and without reference to its peculiar contour; and afterwards, when the pattern is in its place, a fusible metal is poured into the space between the pattern and the plate.

Moulding is an operation requiring considerable space, and with a view of limiting this as much as possible, moulding machines, for work involving much duplication, have been extensively employed. In addition, such machines effect neatness and cleanliness in carrying on the work, and in a measure obviate the necessity of employing very skilled labour; while the increase in the rate of production affords the most economical results.

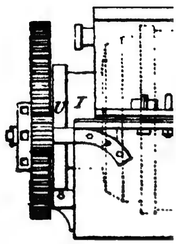
Such a mode as that of Jobson's, described in this Dictionary, p. 1540, is a step in this direction;

and another is the process introduced by John Downie for moulding pipes and hollow cast ware, and applicable to a wide range of articles, generally of cylindrical or spherical form.

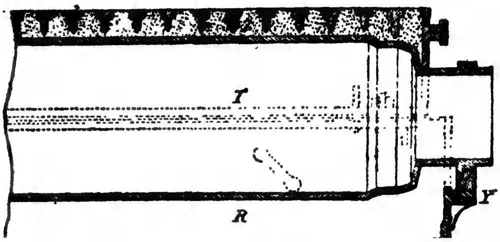
The apparatus employed for this purpose, Figs. 1336 to 1340, is here arranged for moulding a 29-in. socket pipe.

The moulding table R has two edges S S of its face, shown dotted, shaped so as exactly to fit the pattern T, when the latter is raised with its axis level with the edges S, as in Fig. 1339. The

1336.

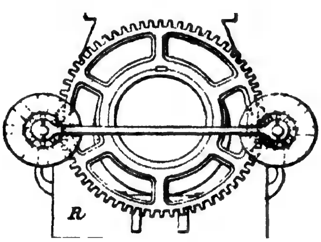


1337.

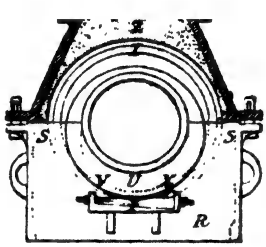


pattern is fitted with a cam or collar U, at each end of which the portion from V to X is concentric with the axis of the pattern, and the remainder eccentric. The cam U rests upon the adjustable bearing Y, and the axis of the pattern is guided by vertical slots in the ends of the moulding table. On causing the pattern to rotate, the eccentric portion of the cam, acting on the bearing Y, gradually raises the pattern till it bears on the point V of the cam, when the pattern is in its highest position, with its centre line level with the edges S of the moulding table, as in Fig. 1339. The flask Z is then placed on the table and rammed up so as to form one half of the mould, and the two faces S S

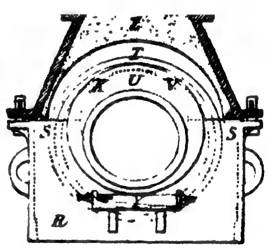
1338.



1339.



1340.



of the table form the parting surface of the mould, being made fair for this purpose. The further rotation of the pattern upon the concentric portion of the cam from V to X retains it in contact with the mould, and thus sleeks the mould until on reaching the point X, the pattern is gradually withdrawn, as in Fig. 1340; the flask Z may then be removed without danger of injury to the parting or junction surface, ready for closing and casting in the usual manner.

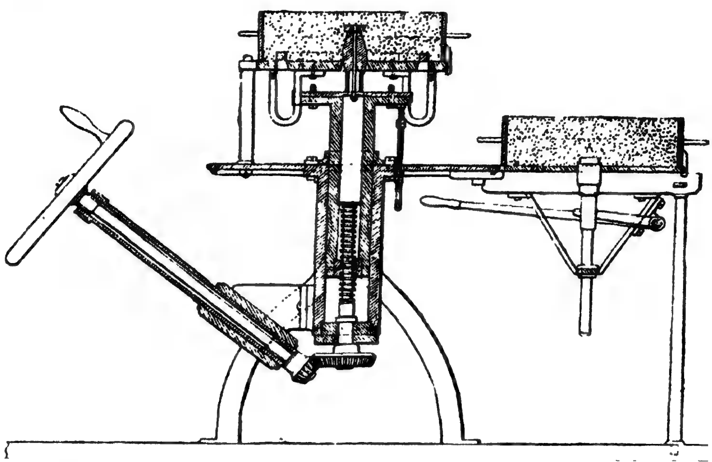
The same principle has also been adopted for making cores or internal moulds, by employing a core barrel made in three portions, two of which are hinged upon the third; the centre spindle is fitted with cams of the form above described, which act upon a V-piece inserted between the two free edges of the core barrel. By turning the centre spindle the V-piece is pushed out or drawn in, thereby expanding the core barrel or contracting it as required; by this means the use of straw or hay in core making is dispensed with.

Howard's moulding machines, Fig. 1341, are largely used in the English agricultural implement works. In Fig. 1341, the pattern shown is that used for moulding plough wheels; two patterns are provided, one for part of the boss, and the other the remaining part of the wheel. The pattern for moulding the wheel is attached to a plate fixed on the top of a hollow mandril, or piston, which slides vertically through the table, and a hollow cylindrical guide fixed below it. This mandril, with the pattern, can be raised or lowered by means of the internal screw, bevel gear, and hand wheel, the height to which it is elevated being regulated by a screwed bar and adjustable nuts. When the mandril is raised, the pattern, or a portion of it, passes through openings made in a plate which forms the bottom of the moulding box, these openings being an exact counterpart of the profile of the pattern. The moulding plate is supported above the main table of the machine by short pillars, and those parts of it which are cut off from the remainder of the plate by the openings, are supported either by brackets of a horse-shoe shape, or by similar means, so that the vertical traverse of the pattern is not interfered with.

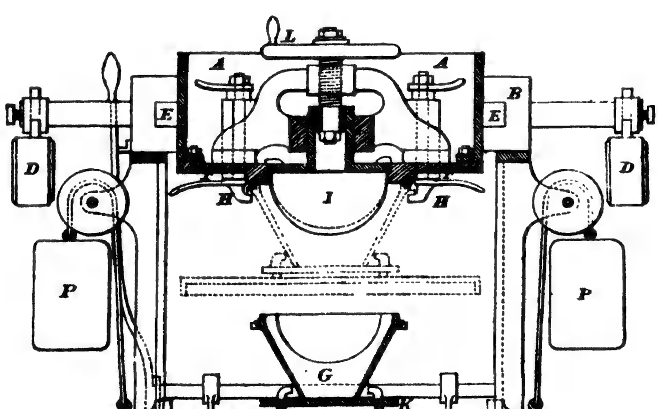
A mould box or flask is placed upon the moulding plate, and the pattern raised until it projects the proper distance through the openings in the plate. The sand is then filled in and rammed in the usual manner, after which the pattern is lowered by means of the screw and hand wheel leaving the finished half mould. The moulding plate gives such support to the sand that patterns without draw can be readily moulded, the edges of the mould being kept perfectly sharp. In moulding plough wheels, a loose metal collar is dropped on the shoulder of the boss pattern, as in Fig. 1341; this is left in the mould when the pattern is withdrawn, and a smooth and chilled surface is thus readily obtained.

The flask forming the remainder of the mould is formed in the other part of the machine shown on the right in Fig. 1341. This consists merely of a mandril, which is capable of being raised or lowered by a lever, fixed upon a horizontal shaft furnished at one end with a hand lever. At the upper end of the mandril is the pattern for forming the remaining part of the boss, this rising through a moulding plate in the same manner as the other pattern.

1341.



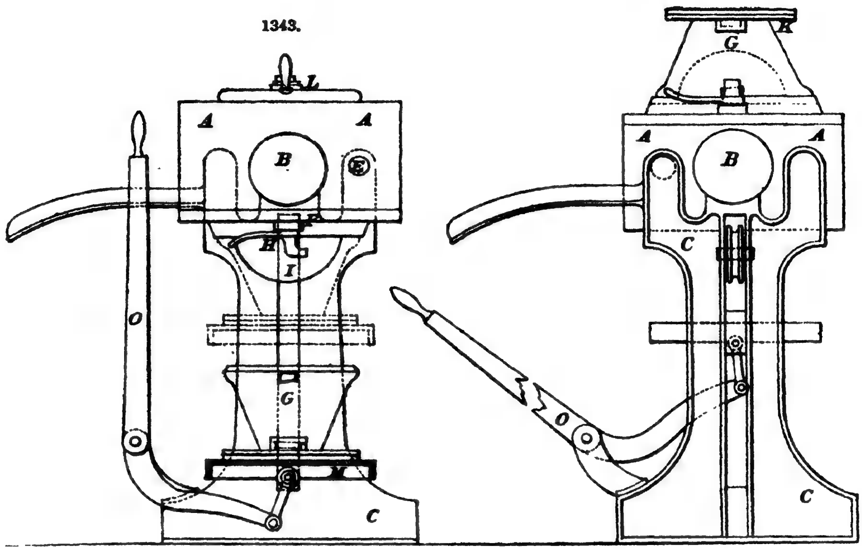
The flasks are kept in their proper position whilst being rammed by lugs, which fall into notches made in the edges of the moulding plates. Sometimes castings with sunk panels have to be made, the panels being filled with a web thinner than the remainder of the piece. For moulding these the patterns are made with openings wherever the sunk panels are to occur, and the moulds shaped by giving increased thickness to the moulding plate at those parts. When the pattern has bolt holes in it, small stops, carried by brackets from the moulding plate, are arranged so as to support the sand in the bolt holes in the same manner as the moulding plate supports the other parts. The moulding plate rests upon pillars fixed to the table of the machine, and it can thus be readily removed when it is desired to change the pattern, which can be changed by merely knocking out the keys passing through the bolts, which fix the plate to which it is secured to the mandril head. Many of the machines are made with special arrangements for removing drawbacks.



A moulding machine of most ingenious construction was introduced some years since by R. Jobson. It is shown in Fig. 1342. A A is the moulding table or bed, consisting of a rectangular cast-iron box, open at top and bottom, and furnished with a large cylindrical axis B B at each end, 6 in. diameter, turning in bearings on the side frames C C. The axes are prolonged at the ends, and counterbalance weights D D attached to them by arms, which can readily be adjusted by lengthening or shortening, so as to balance the table with the mould upon it, leaving it free to turn upon the axes. The table turns half round, as shown by the two positions in Figs. 1343 and 1344,

being prevented from turning further by stops, E E, upon the ends of the moulding table, which catch in notches on the top of the frame C. On the top of the table A a plate F is fixed by screw bolts, carrying the moulding box G, which is secured upon it by two inclined catches with handles H H, the plate F forming the ramming board upon which the pattern I is fixed, and the moulding sand rammed upon it in the ordinary way. The machine is shown as arranged for forming 8-inch mortar shells, the pattern I being a hemisphere.

1343.



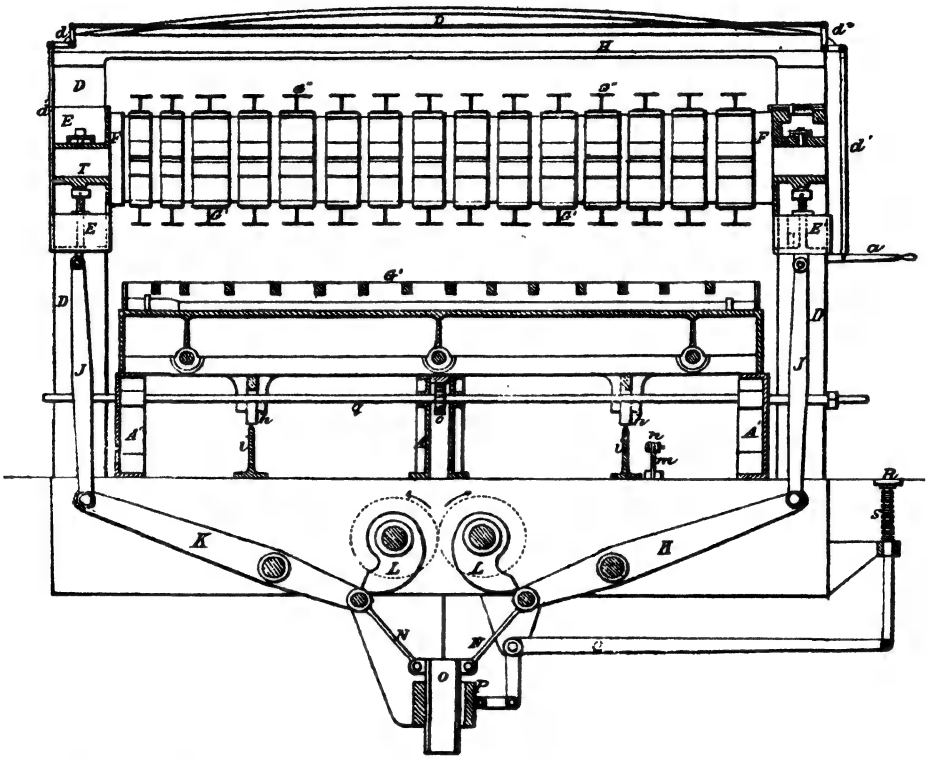
As soon as the sand is rammed, the cover plate K is put on the box, by sliding it on the inclined snugs which hold it fast; the whole is then turned over with the moulding table into the reversed position, as in Fig. 1342; this being effected by the simple pressure of pushing home the cover plate K, since the whole is balanced and turns freely upon the axes. In moulding shells, the pattern I is then withdrawn from the mould, sufficiently to make it clear the sand, by means of the screw and hand wheel L. A rising platform M, which slides in vertical grooves in the side frames C C, is then brought up by means of a lever O, to touch the cover plate of the box which is now at the under side, and the box is liberated from the moulding plate by releasing the two catches H H, simultaneously, by means of the second handles, fixed on the other ends of the spindles for this purpose. The whole is then in the position shown by the dotted lines in Fig. 1342, and the platform descends, by means of the additional weight upon it, to the bottom position in Fig. 1342, the platform being counterpoised by the balance weights P P. The mould is then removed, by sliding it off the platform on to a little railway placed at the same level, and the machine is made ready for repeating the operation, by screwing down the pattern to its right place, and turning back the moulding table to its former position, ready to receive a second empty box.

The principle carried out in this machine, of turning over the whole moulding table with the mould and pattern upon it undisturbed, has the effect of saving all the labour of lifting the moulds.

Figs. 1345 and 1346 are of an arrangement designed by H. Cochrane for pipe moulding, in which a series of mechanical rammers are made to act successively on the sand in the mould box; the first set of rammers being formed with their surfaces to correspond with the pattern to be moulded, while the following rammers have their acting surfaces approaching more and more to that of a plane as the filling in of the sand proceeds, the object being to ram the sand equally into every part or space of the mould box. A A′ is the framing of the machine, upon which are placed movable tables carrying mould boxes C, at each end of the frame upright guides D enable the sliding blocks E, carrying the rammer frame F, to move up and down, these guides being tied across the top at H; the rammer frame F has in this instance four differently formed sets of rammers G′ G″; G′ being intended to act upon the first charge of sand filled into the mould boxes, G″ on the second, and so on, the rammer frame being for this purpose raised, and at the same time turned a quarter of a revolution, and then made to descend rapidly. Beneath the sliding blocks E are other blocks E′, carrying adjusting screws, upon which E rest, and thus serve to adjust the exact position of the rammer frame in relation to the mould boxes. The blocks E′ are connected by links J, to rocking levers K, receiving motion from the rotating cams L, driven in the direction of the arrows by the gearing M, from the mill shaft M′; they thus raise the sliding blocks and rammer frame into the position, Figs. 1345, 1346, when as the cams recede from the levers, the rammer box is free to descend by its own gravity. In order to regulate the force with which the rammer frame descends, the levers K are connected by links N to a cylinder O, which moves up and down through a collar P, this can be tightly pressed against the cylinder by the bell-crank lever Q, worked from the treadle R; the collar P is usually kept off the cylinder by a spring S pressing the treadle upwards. The rammer frame turns freely upon strong pins T, carried by E, and provided at one end with four spring rollers, which can be pushed back into recesses in the end

of the frame, but which are ordinarily pressed forward by springs, so as to project beyond the frame F. In the raising of the rammer frame, the roller, which for the time being is situated centrally, comes in contact with the lower end of a stop plate, and the frame F, continuing its upward motion, is forced to turn on the pins T until it has attained its highest position, when the rammer frame will have performed a quarter of a revolution. The other rollers, in turning with the frame, are made to slide against an inclined surface formed at the top of the block E, which presses them

1345.



back, and allows them to pass the projecting stop plate in their downward motion. In order to hold the frame securely in the correct position after being turned, a spring bolt is made to spring forward into an eye formed in the frame, the bolt being retained in a backward position during the ascent of the frame, by means of hinged arms connected to the bolt, the ends of which, in the lowest position of the blocks E, pass into grooves in the guides, and are made, by the curved form of these grooves, to draw the bolt back out of the eye during the first part of the ascent, while the upper part of the grooves are formed so as to allow the arms to spring forward with the bolt.

For holding the rammer frame in its raised position while the mould boxes are being changed, spring catches C are employed, which project out between the guides D below E′, but which during the operation of the rammer frame are withdrawn by means of the lever *a*, and the connection *d′*. The tables carry the half-patterns of the pipes to be moulded, which are arranged to be lowered into the tables by means of the cams *f*, actuated by the worm and worm wheel *g*.

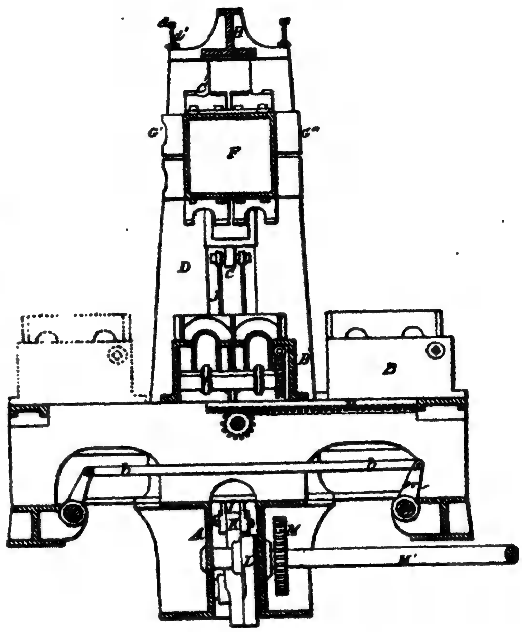
While the operation of ramming the mould box on the table B′ is going on, another mould box is placed on the table B, and filled with sand preparatory to being rammed in its turn. When the ramming is complete its table is moved from under the rammers into the position in dotted lines in Fig. 1346, and B is moved under the rammers. For this purpose the tables are provided with wheels *h* running upon rails *i*, which rest upon the framing A, while the operation of ramming is going on, at which time the tables also rest on the framing A. But when it is desired to shift the tables, the rails *i i* are raised slightly by means of cam surfaces on the two shafts *k*, which are simultaneously turned somewhat for this purpose by a hand lever and connecting levers *m n*. By this means the tables B B′ are both raised slightly off the framing A′, and they are then made to move into the required positions by means of the pinion *o*, in gear with the rack *p*, fixed to the tables and driven by means of the shaft *q* and crank handle, after which the tables are again lowered on to the framing, and the ramming of another mould box is proceeded with, while, at the same time, the box with prepared mould is removed from the table B′ and replaced by an empty mould box.

In the earliest method of making toothed wheels, the teeth were chipped out by hand from the solid edge of the wheel, upon which they were set out and shaped to template. Subsequently the

teeth were formed on a wood model of the wheel, and moulded from this model according to the plan in general use.

Wheel moulding from patterns thus made involves the necessity of having a separate expensive pattern for each wheel that differs in form and pitch of teeth, as well as in diameter. The result has been a vast collection of tooth-wheel patterns, to meet the requirements of ordinary trade demands; and this stock has become so costly, in the expense of construction and of the storage space occupied, that it has led to an objectionable limitation in the range of pitch of wheels, in order to reduce the extent of the stock of patterns. The use of wood patterns for entire wheels involves further, the practical objection of liability to distortion, both in the general contour of the wheel and in each tooth, owing to the irregular effects of expansion and contraction in the component parts of the pattern, as well as the unavoidable risk of variation in the forms and dimensions of the several teeth, in consequence of the different finish that each receives. The uncertainty, too, attending the drawing of an unwieldy pattern from its mould, and the distortion of the pattern that occurs from its lying in damp sand for a considerable time, are additional obstacles to the manufacture of a toothed wheel from the ordinary wood models, with the correctness that is desirable.

1346.



The only method of overcoming these difficulties is by employing a small segment as the pattern, and moulding the entire toothed circumference by repetition of this small portion; employing mechanical means for lowering and raising it, and for spacing out the teeth round the circumference of the wheel, so as to obtain the same certainty of accuracy throughout, as is shown by a wheel divided and cut in a machine. This process was introduced by P. R. J...n, and carried out with greatest accuracy; and until the advent of his most valuable machine ... be said that no really correct toothed wheels were cast.

...e object of G. L. Scott's wheel-moulding machine, described at p. 1558 of this Dictionary, ...n to extend the application of this process by the use of a portable machine, of small size and cost, that can be easily applied for moulding a toothed wheel in any part of a foundry.

Another good machine for wheel moulding is that invented by Wm. Whittaker, Old...

A is a circular framework cast in one piece, B is a circular table, and to this is keyed a dividing wheel M, containing 240 teeth, by which the table is revolved, and each revolution is divided into the number of teeth required in the wheel to be moulded, motion being communicated through the change wheels O P, from the handle N, to the worm C, working in the worm wheel M, both the dividing wheel M and worm C being well protected from the dust and grit. D is a turned pillar fitted in the socket R, in which it slides up and down to suit the depth of wheel to be made, and supported by the rack E. The pillar will revolve to obtain the radius required, from the centre J to the pitch line of the pattern T. F is a horizontal slide, used chiefly in making worm wheels. At the end of the slide F is the vertical slide G, for lowering and raising the pattern T to and from the mould.

Having ascertained the sizes of wheels to be made, it is necessary to set them out full size in section on a drawing board, in order to get the proper form of strickling board and core box for the arms. It is also necessary to draw in full a short segment of rim, showing the proper form and size of a few cogs. The block or segment pattern is made with two teeth only, as with Scott's machine.

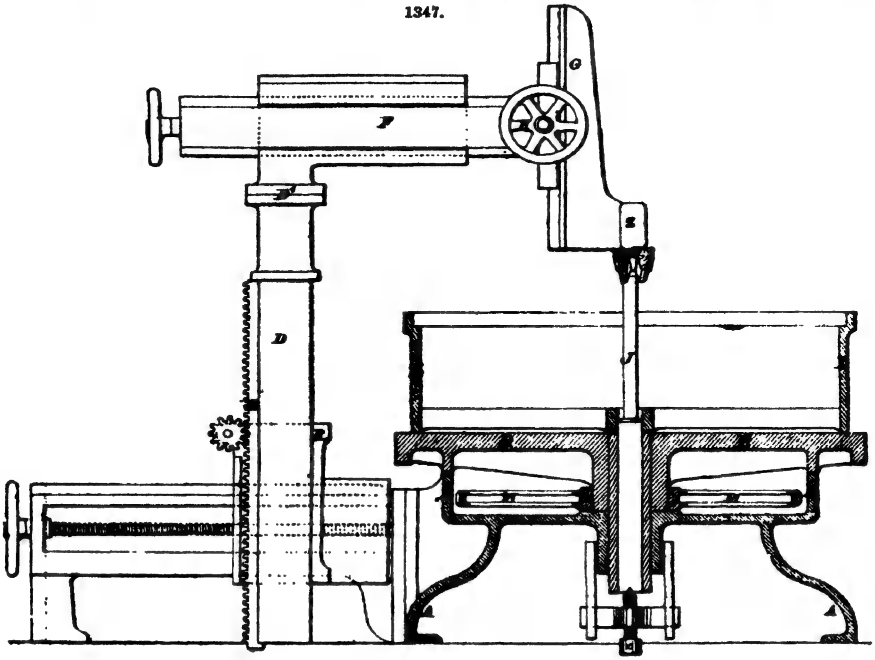
The next part of the pattern is the strickling board, Figs. 1349 and 1350, the former for bevel and the latter for spur wheels. These boards are shaped to the exact section of the wheels intended to be made, the edge *a b c* forming the lower part of the mould, or that part which is to receive the teeth; and the edge *d e* forms the mould for the back part of the bevel, or top side, of spur wheels, or in other words *a b c* form that part of the mould made in the bottom moulding box, and *d e* form that part of the mould made in the top box; ...

... ...n, and L...

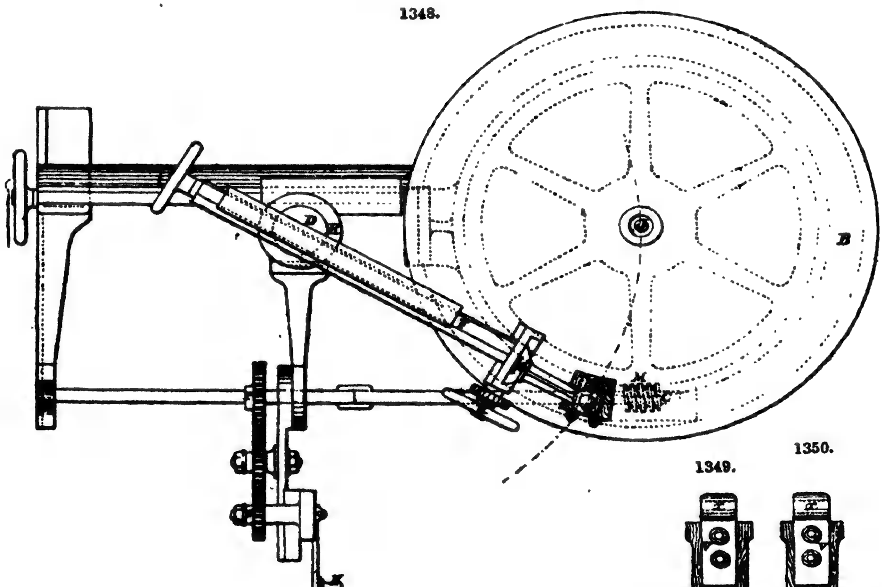
The moulding boxes to be used with this machine are bored, turned at the joints, and fitted ...gether in pairs, the bottom box L only being used on the table of the machine. The slides F G, to which are attached the whole of the top part of the machine, are bolted to the top of the pillar D through the flange D[1]. By revolving the pillar D, the whole of the slides F G and appendages are

moved from over the table B, leaving the table quite clear and free from all obstructions. The moulding box L is then placed on the table B. The centres of the table and moulding box are bored one size to fit the centre spindle J, which is dropped into both centres, after placing the box

1347.

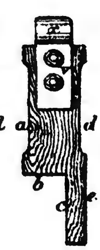


1348.



1349.

1350.



on the table. The box is then filled with sand, and rammed in the usual way, leaving sufficient space for filling or facing up the mould with new sand.

The striekling board, Fig. 1349, is then applied; the hole x in the bracket V, to which the

strickling board is attached, being bored to fit the centre spindle J, on which it revolves, supported in the centre by a hoop on the spindle J, and the edge *c*, resting on the top edge of the box L. By moving the board round, the spindle describes the proper form of mould preparatory to receiving the teeth.

The segment, or pattern T, is screwed to an iron angle bracket, and secured in the socket Z. The upper portion of the machine G Z is then brought in position over the mould and secured; the proper radius and position being ascertained, the pattern is lowered on the sand bed already prepared by the strickling board.

Prior to this the number of teeth in the wheel intended to be moulded being found, the operator puts on the requisite change wheels *o p*, coinciding with the dividing wheel and the wheel to be moulded. There is a list or table of changes sent with each machine, showing what wheels to use and how to place them.

Say, for example, there is a wheel to make with fifty-five cogs, they would be placed, according to the table, in the following order ;—

No. in Wheel to be made.	Handle Shaft.	Worm Shaft.	No. of Turns a Tooth.
55	60	55	4

If the machine is heavy to work, through having a large box filled with sand, the relieving screw W is applied to the bottom of spindle J, and the machine will then work with ease.

The workman then proceeds with filling in between the two teeth in the pattern with sand, and having rammed the sand to sufficient and uniform hardness, he raises the pattern from the sand by the hand wheel H, working a pinion and rack which raises the vertical slide G to which the pattern is attached, and is held when raised by ratchet wheel and retaining pawl.

The requisite number of turns is then made with the handle N, and the pattern lowered into the mould by the hand wheel H. On lowering the pattern in the sand for the second tooth, the operator should particularly notice, when lowering, whether the pattern tooth displaces or presses too hard on the sand tooth, and if it should do either, the wheel he is making is too small in diameter for the pitch and number of teeth intended, and it is necessary to make the wheel a little larger. This is readily accomplished by releasing the pillar D in the socket R, where it is secured whilst the moulding is in process, and then increasing the radius J T, Fig. 1348. If, on the contrary, it is found that a space is left between the pattern tooth and the sand tooth, on lowering the pattern for the second tooth, the wheel is too large, and the radius requires contracting. If the segment tooth only just touches the sand tooth without displacing the sand, the wheel is then the proper size. It always indicates, on making the second tooth, whether the mould is right, and if it is right, the workman proceeds to fill between the two teeth of the pattern with sand as before, and so repeats the operation until the whole wheel is finished.

The top part or box does not require to be placed on the machine at all. It has a small hole bored through the centre, in which is fitted a spindle, and on this spindle the bracket V fits exactly, as in the bottom part; the board does not require taking off the bracket, but both are inverted together, and the edges *d e* serve the same purpose in the top box that *a b c* did in the bottom box.

The use of gear wheels to effect the regular movement of the table in wheel-moulding machines has been objected to by some, and in Bellington and Darbyshire's machine the use of geared wheels is done away with, and their place is taken by adapting to the table a perforated rim or ring of metal, called the dividing ring, which is placed above the periphery of the revolving table, and arranged to operate in conjunction with a locking device. The ring or rim is made to answer the same purpose as the dividing plate on a wheel-cutting machine, and to this end is perforated with a series of sets of holes in parallel lines around its periphery.

The table is held firmly in the required position by means of a screw pin, the end of which engages with the holes on the dividing ring, and after each tooth of the wheel has been moulded, the screw or pin may be withdrawn, until the next hole in the dividing ring is brought opposite to it, by the turning of the table by means of the screw and worm wheel, to be again held in position during the operation of moulding the next tooth. By this arrangement the revolving table itself is fastened directly and securely in position, at a point outside its largest diameter, thus giving to it a maximum of steadiness, which cannot be attained by any arrangement of geared wheels.

The cost of patterns for machine-wheel moulding is merely nominal, compared with the making of whole patterns, and if destroyed these are easily replaced. Again, the storage for whole patterns is generally very large and expensive, whereas if made by machine the storage will not exceed 10 to 20 per cent. of the room occupied by whole patterns. Whole patterns are very subject to get out of truth by variations of temperature, and it is very costly, even if at all practicable, to keep a room at one temperature. On the other hand, if the blocks for wheel moulding get out of truth, they are soon replaced at a very small cost, and wheels made by machinery are certainly more accurate than wheels made from a pattern.

The drying stove of a foundry should, if possible, be built contiguous to the moulding shop, with lines of railway running into it, through openings in the partition wall. The work to be dried can then be run into the stove, from various parts of the moulding shop, and when dry, should be withdrawn from the other side ready to be placed in the pit for pouring. In this way the continual flow of work is kept in one direction, progressing towards completion, and time and labour are much economized, especially where large heavy work is in hand.

The stoves are generally built in sound brickwork, and of such shape and dimensions as are required for the kind of work to be executed, and are provided with appliances for entering and

withdrawing, or shifting the position of the articles to be dried. The walls, especially if exposed to outside air, should be built double, with an air space between them.

In some cases it is possible so to arrange the stoves that their heat shall be greater towards that end where the cores are withdrawn, as in the case of a pipe foundry, where the cores are tolerably uniform in bulk, and will therefore dry in regular rotation, so that the wet cores on entering can be placed in the coolest part, and be gradually advanced as they dry to the hottest part, previous to being withdrawn. In the majority of foundries, however, such a systematic course cannot be adopted, owing to the varying bulk of the cores and moulds to be dried, and the necessity that exists for the men to be able to get at them to apply the blackwash, which is generally done within the stove.

The stoves are sometimes built with cast-iron floors, without any rails, the trucks are then wheeled along the rails to the entrance of the stove, but when in the stove they run upon the flanges of the wheels, which are made rather broader than usual to give them a good bearing surface. This plan considerably lightens labour, as the loaded trucks can thus be more easily moved from one part of the stove to another, than when obliged to follow the line of rails.

If the stove is required to be of any considerable length, it is desirable to provide it with sliding iron partitions, by which it can, when necessary, be divided into compartments, with doors to each, so that the articles in any one part of the stove can be made accessible, without delaying the drying of the others. During the time that any one compartment is thus separated from the remainder, the current of heated air must be diverted past it, by means of a flue provided with valves for regulating the flow of the air.

An ordinary drying stove consists of a simple brick chamber, with large plate-iron doors at one end, which can be thrown wide open. The three sides are built in 9-in. brickwork. In one of the sides is a fireplace, which can be supplied with fuel from the outside of the stove, and may be shut off by a closely-fitting iron door. In the opposite side of the fireplace is a flue leading to the chimney; this flue is placed low down. An arched brickwork dome covers the chamber. Iron shelves are arranged along the walls for drying small cores and boxes on. A line of rails which is within the sweep of a crane, leads into the stove, and any heavy mould which is to be dried may be laid upon a car running on this track, and both car and mould are pushed into the stoves, the doors closed, and fire put in the furnace. The size of a drying stove is varied according to the size of the castings commonly made in a foundry. A stove of 12 ft. in all directions, and 7 ft. high, is a good-sized stove. When there is no occasion for employing a large stove, a small one is selected by preference, because it works faster, and with less fuel.

One plan of drying moulds consists in forcing air through mains below the foundry floor, and having openings in the bottom of each pit, within which the moulds are placed. Over the opening into each pit is placed an iron basket full of burning coke, and over the top of the pit a cover of plate iron is let down, having a small opening for the escape of the heated air. By thus blowing heated air amongst the moulds they are quickly dried.

In order to dry any material in a confined space, it is necessary not only to heat the air in that space, but to change it before it becomes saturated with moisture, otherwise the material is simply steamed, not dried. It would appear therefore that a high temperature with a brisk current are the most favourable conditions for drying, but with regard to cores and moulds, the limit of both these powers is soon reached. Supposing a low temperature is adopted with a very rapid current of air, the surfaces of the loam are very liable to crack; whilst if the low temperature is used with a slow current, the loam in drying gradually gets so dense and consolidated as to lead to a probable failure in the casting from blowing. If, on the other hand, the temperature is forced beyond 500° Fahr. with a slow current, the moulds and cores dry unequally, and the steam which is generated splits off pieces, and thus spoils the cores and moulds, besides destroying the fibrous qualities of the haybands, tow, or horse-dung used for binding the loam, and other materials used in their construction.

The speed of the current must be regulated to suit the work being dried, and observations upon the amount and rapidity of the evaporation going on in the stove should be frequently made, and carefully noted.

For heating the stove, a regenerative firebrick furnace has many advantages. It is easily regulated, can be heated with refuse coal, and the heated air is delivered into the stove much more free from dirt and soot, than when the stove is simply used as part of a flue for the products of combustion from the heating fire to pass through, on their way to the chimney.

In his 'Études sur la Ventilation,' Morin gives some formulæ which will be of service to anyone having to design foundry stoves, and who may wish to calculate somewhat closely the supply of heat, the volume of air, draught, height, and area of chimney required, and similar details.

The foundry pits necessary for heavy work are either sand pits or open pits. The former are filled with sand, to the level of the floor, which is dug to form a sufficient cavity, not only to enable the loam mould to be lowered into it, but also to allow the labourers to fill and ram the sand in again, firmly all round the loam mould, as a sufficient support to enable it to resist the pressure of the fluid metal inside it.

Sand pits are used where the loam mould is built up, both in core and cope, upon a skeleton framework of common or loam bricks, or in such other manner as not to have sufficient stiffness in itself to resist the pressure of the liquid metal. The necessary support for the cope, or external portion of the mould, is here obtained by the filling in around it of the solidly rammed sand.

As to the cores, when these are circular in section, they are not found to require much support beyond the brick skeleton, but when they are irregular in shape, they are strengthened by stiffening pieces, or struts of wrought iron, or rings, applied according to the circumstances of the case.

Sand pits are almost invariably used for the larger description of castings, and even where small work is the rule, a sand pit is occasionally required. It should be about 4 ft. larger in clear space all round than the largest mould which it is expected to accommodate, in order to allow

ample room to dig out the sand and fill it in again around the mould. The cylindrical form is that best adapted for a sand pit; it should be surrounded with a brick wall, to prevent the sides from falling in, when the sand is removed. The depth and diameter of the pit depend upon the description of work it will be used for, but as a general rule castings of large diameter are seldom very deep, and those which are of great height are seldom of large diameter.

Exceptional circumstances require special appliances to meet them, and it is scarcely worth while to constantly dig, wall, and fill in with sand, a very wide and deep pit, whose utmost capacity may perhaps only be tested once in twenty years. To partially overcome this difficulty, it has been proposed to excavate a central pit of considerable depth, surrounded by one of much larger diameter, but of less depth.

Before filling in the pit, the sand should be screened, and wetted, and should then be thrown in, in successive layers, being well and equally rammed down all the time, by labourers in the pit. If this operation is carefully performed, the sand will bear digging out from around the mould, and will stand up firmly like a wall. If, on the contrary, sufficient attention has not been devoted to this, the sand will come out unevenly, and will fall down in masses from the sides. In the case of large pits, this is a source of considerable danger and loss.

If the mould and casting have not yet been removed, the fallen sand must be dug out; whilst should a fall occur just after the core of a large mould has been lowered into the pit, and before the cope has been properly adjusted in its place, it is most probable that the core will be damaged by the falling sand, or the least evil will be, that it will absorb some moisture from the damp sand.

In digging out or filling in deep pits, some precautions should always be taken to protect the men against the falling sand, by placing struts and poling boards against the sides, as is usual in all deep excavations, and is the more necessary with such material as sand. In digging out the sand from large pits, it is necessary to caution the men on the upper bank not to walk too close to the edge, so as to avoid bringing down the sand upon the men below.

When the pit exceeds 8 ft. in depth, it is usual to excavate the sand by the ordinary staging process, having labourers on each stage, to throw the sand to the stage above, until it reaches the bank, where more labourers must be stationed to shovel it back from the edge of the pit, which must be cautiously done.

The sides must be supported with struts and stout poling boards, and sometimes rings of angle iron, in three or four segments, are lowered into the pit, and bolted together, thus forming a very strong circular support for the edges of the bank. Into the interval between the ring and the poling boards, hard wood wedges are firmly driven. One great advantage in the use of angle-iron rings to support the poling boards, is that cross struts are thereby avoided, and the rings and poling boards need not be removed until after the mould has been lowered into place, and it is necessary to ram in the sand around it.

One or two light ladders should be left in the pit, until it is so far filled in, that the men can leap out on to the bank in case of a sand fall.

The walls of dry pits are generally built of brick, sometimes of stone, and the bottom should be laid with a slight fall towards the centre. If the soil around and beneath the pit is wet or shifting, a good concrete foundation must be put in, and concrete must also be run in around the walls, which must be built strong enough to resist external pressure. In a watery soil, the whole mass of the casing must be of sufficient weight to counterbalance its displacement, so as to ensure its not being lifted, or floated, bodily upwards out of its site by water.

Such an accident is most unlikely to occur, except where a pit might be placed near a river, whose rising water could permeate the soil around the pit. But as a rule a waterlogged soil is, and should be, avoided for the site of a foundry. These pits are occasionally lined with thin wrought or cast-iron plates; when casting in such pits, however, precautions must be taken that the molten metal does not come in contact with iron casing, as it would probably crack or damage cast-iron plates, or stick in lumps on the wrought iron.

Open pits are simply dry pits with flat bottoms, placed below the sand floor of the foundry, within the sweep of the cranes, and of such a depth as will allow the moulds to be stood within them, without rising much above the top edge of the pit. Open pits are employed where the loam or dry sand mould is built up within a flask of cast or wrought iron, which casing is sufficiently strong not only to support the mould, but also to take the thrust which comes upon the mould, when the metal is poured into it. The dimensions of the open pits are regulated by the size and form of the castings for which they are intended.

In most cases where any large castings have to be made in numbers of a similar size and shape, such as large pipes or columns, it is more economical to provide iron cases for the moulds, whether these are of dry sand or loam, and thus to be able to use the open pit when pouring. The moulds must be properly secured in position in the pit by struts and stays, unless of such a form as not easily to be displaced.

When it is necessary to withdraw a casting from the pit, the sand should be dug out all round down to the bottom of the mould, before attempting to lift the casting out by the crane. This is a point to which sufficient attention is frequently not given, and the casting or the crane chain will probably be strained. One great advantage of casting in deep sand pits is the power it gives of casting bodies, such as large pipes and cylinders, in a vertical instead of in a horizontal position. It is well known that casting in this manner tends to improve the metal in the body of the work, and affords a ready means for extracting from the casting dross and air-bubbles, which rise into the open part or rising head of the mould.

To reap the full advantage of this tendency, the metal should not be poured directly into the top of the mould itself, as it would probably fall with too great a blow, and would in falling carry a large quantity of air with it. The plan which is found most successful is to convey the metal by vertical gates to the lower part of the mould, to pour the metal into these, so that it flows upward in the mould, when the air-bubbles and dross will float to the surface, and be then easily removed,

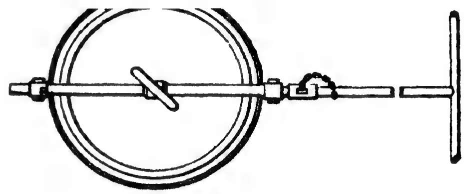
whilst the body of the casting will derive all the advantages which accrue from the pouring with a head of metal.

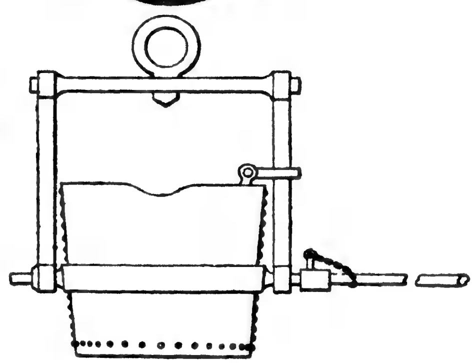
A foundry must be well provided with ladles, varying in size from the smallest, which one man can easily carry, up to those capable of holding two, three, or five tons. Of the smallest size, which are similar in form to Fig. 1352, but generally made with ladle, trunnions, and handles in one piece, a good many should always be kept in stock; of the larger sizes, the number must of course be determined by the class of work it is usual to contract for in the foundry.

Figs. 1351, 1352 are a plan and elevation of a common form of heavy ladle, generally made of boiler plate, which should be strong and thick, with double-riveted butt-joints, heads of the rivets inside, and a strong angle-iron ring round the bottom.

The shape is cylindrical, with the bottom slightly concave inside, and it is usual to roughen the internal surface with a view of giving a better hold for the loam coating. The plates of the ladle are frequently perforated with a number of holes, about half an inch diameter, allowing an egress for the gases, which are generated in the lining, when the molten iron is run into them from the cupola.

1351.





1352.

The body is surrounded by a strong iron ring, from which two trunnions project; over these, the holes in the frame fit, the upper bar of the frame having a stout eye, for slipping on to the hook of the crane chain. A loose swinging fork is arranged on one of the upper edges of the ladle, and by throwing this into, or out of, gear with the side of the frame next to it, the ladle is kept vertical or swung over at pleasure. A handle fits on to the prolongation of one of the trunnions, and is a rough means of regulating the quantity and rate at which the metal is poured.

Before commencing to line the ladle, it is advisable that it should be slightly heated; the furnaceman then gets inside it, and having coated the interior with a wash of clay of about the consistence of cream, he proceeds to apply the loam to the bottom of the ladle, in a uniform coating from 1 in. to 1½ in. thick, using the utmost precaution to force it into close contact with the plates at all points. In working upwards the thickness of the lining is slightly reduced, and the covering of the lips must be rounded off, so as not to oppose any uneven surface to the flow of the metal, whilst at the same time it must be prevented from coming in contact with the iron of the ladle. When the lining is completed, the ladle is allowed to stand, until the loam has dried sufficiently to allow of the ladle being turned upside down, without disturbing the lining. A fire is then lit beneath the ladle, so as to completely dry the lining. The ladle must be slightly tilted on one side, to allow the damp air and smoke to escape. The nature of the fire thus applied somewhat depends upon the convenience of the works, but one of the simplest and readiest modes is to place a pile of ignited coke on a piece of old sheet iron, and run it under the ladle.

If any cracks are observed in the lining during the process of drying, they must be filled up with moist loam, and when the whole is perfectly dry and uniformly covered, without cracks or flaws, a coating of thick blackwash is applied. When about to toss the metal into a ladle, an old piece of plate should be placed in a sloping position, resting against one side of the bottom, so as to prevent the first force of the current of metal from coming into contact with the lining; this plate must be removed with the tongs, when there is metal enough in the ladle to receive the flow of the falling metal. The "breaking of the iron" in the ladle is useful as an indication to the founder of its temperature.

The currents are more rapid, and the bright lines dividing up the surface are more irregular and transitory when the metal is first run into the ladle than afterwards.

By a close observance of this curious phenomenon, the founder is enabled to judge the right moment for pouring, as it is seldom advisable to do so when the iron is at a much higher temperature than is necessary to ensure its penetration to every part of the mould, and making a clean sharp casting. Small ornamental work must be poured at a higher temperature than large, heavy castings.

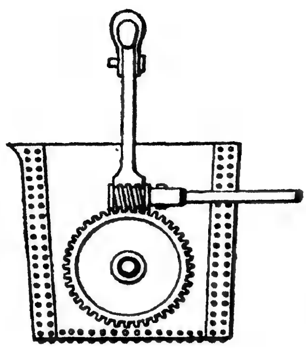
If the metal in the ladle is considered to be too hot to pour, a few pieces of perfectly dry, clean scrap iron are plunged into the ladle, where they will absorb some of the excess of heat, in the process of being melted. The iron thus put into the ladle has a strong tendency to float; it must therefore be forced down with the tongs, but the greatest care must be exercised not to damage the lining in so doing.

A convenient mode of tipping the ladles is obtained by the arrangement in Figs. 1353, 1354. The strong wrought-iron cross-head is brought down on each side to nearly the bottom of the ladle, where it is bent round extra strong lugs or trunnions. Upon one of these trunnions is keyed a cast-iron worm wheel, which is geared into by an endless cast-iron screw, carried by bearings

attached to the side bar. The end of the axis of this screw is square, so as to fit the socket of the long shaft, which is caused to rotate by means of a capstan wheel, fixed at such a distance from the ladle, that the man working it shall not be inconvenienced by the heat of the metal in the ladle.

This arrangement enables the ladle to be quickly, and safely, tilted to any desired angle. In order to ensure its steadiness when in an upright position, the usual forked catch with a hinge is

1353.



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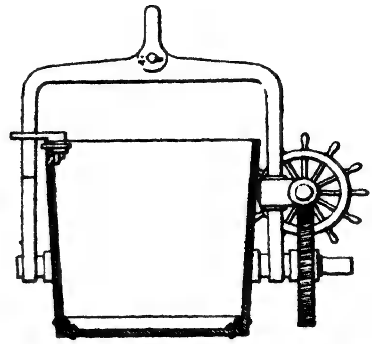
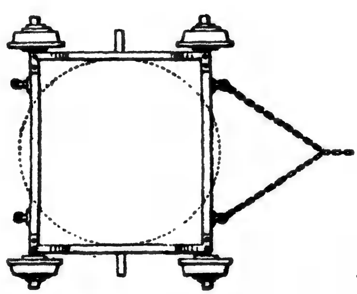
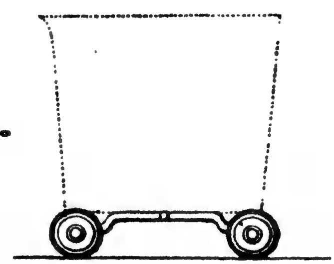


riveted on one side of the ladle; the fork embraces the vertical arm of the cross-head, thus preventing any movement out of the perpendicular until the catch is disengaged.

For conveying the filled ladle from the cupola to the mould, an overhead traveller can be used, or a small but strong wrought-iron truck, Figs. 1355, 1356, running on light rails, may be employed, so arranged as to run the ladle within command of the sweep of the crane used in pouring. The rails should be laid a few inches below the usual floor level of the shop, and when not in use, be covered in with sand, to protect them from any liquid metal that may be spilt.

1355.





The chains for moving the trucks along the railway are sometimes drawn by manual labour, but a more steady motion is obtained by winding the chain upon a barrel at the end of the line of rails.

Having the ladle conveniently placed over the mould, the foreman in charge will direct the men to commence pouring. A skimmer should stand on each side of the ladle, if it be a large one, to remove all the slag and other impurities floating on the surface of the metal, and to prevent as much of them as possible from flowing into the mould. For this purpose they use a skimming tool, consisting of a flat blade of wrought iron fixed on to a long handle of round bar iron. To prevent the oxidation of the surface of the metal, powdered charcoal is plentifully thrown on it. But in any case a certain amount of dross will be found on the top of the ladle, and some of it will evade all the dexterity of the skimmers, and flow into the mould, to the great risk of spoiling the casting.

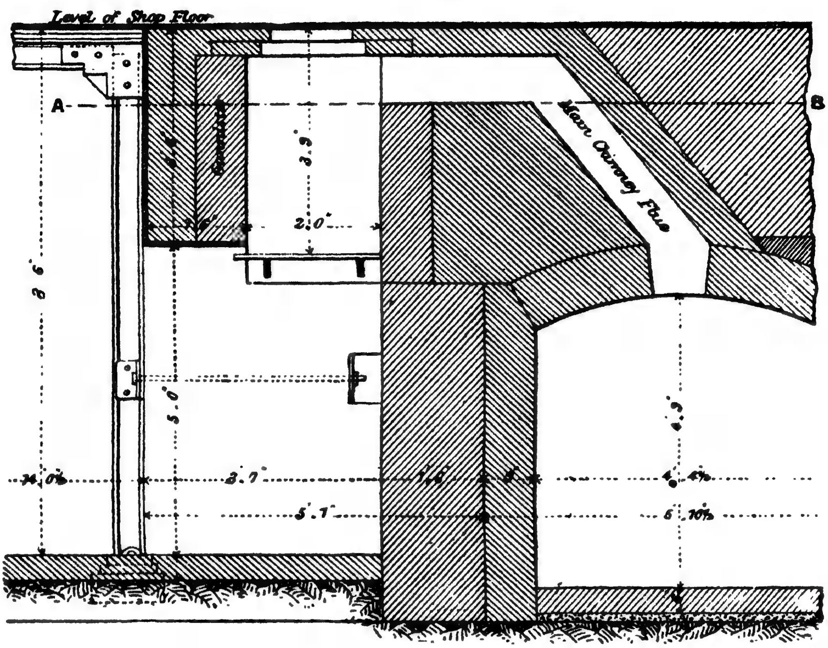
Cast Steel.—From the time of Huntsman the principal improvements in the crucible processes of steel making have been that a small proportion of manganese, in one form or another, is generally added to the metal; that the size of the pots has been increased; that two, and sometimes four, are heated in each furnace, instead of only one, and in many works the regenerative gas furnace is now in use for melting, in place of the pot-hole fired with coke; that very much milder, less fusible metal is now often melted; and that, as the knowledge of the chemistry of the subject has advanced, every possible mode of making steel in crucibles has, at one time or another, been either tried as an experiment or worked on a commercial scale.

Figs. 1357, 1358 are examples of the furnaces now used for melting steel in crucibles, and represent the ordinary pot-holes used at Sheffield, in which coke is the fuel. Each hole or furnace is a simple rectangular chamber, communicating near the top with a large main flue, which is common to a row of furnaces. The tops of the furnaces are on a level with the floor of the melting shop, and the grates are accessible from the cave below. Each furnace is covered by a square

fire-tile, or quarry, fixed in a wrought-iron frame, from which a handle projects in front. The furnaces are lined with ground ganister, a variety of millstone grit that is found near Sheffield, and is of great value as a fire-resisting material. When the furnace is to be relined, a wooden mould is put into it, and the ground material rammed round.

The pots almost invariably used are of fireclay, mixed with a little coke-dust, and sometimes also with a little burnt clay, old ground pots, to make the mass more porous, and thus diminish the

1357.



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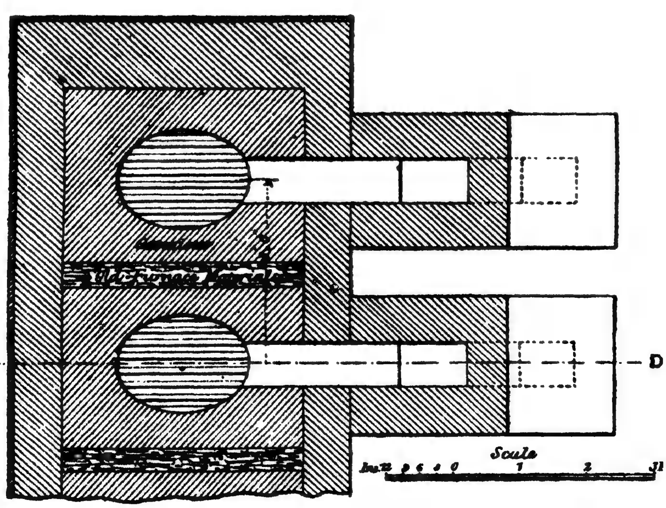


risk of cracking. The mode of making and annealing the pots is described in this Dictionary. The pots vary much in size: thus, some hold a charge of only 28 lb., and others from 40 lb. to 45 lb. The present tendency is towards the use of large pots, holding 55 lb. to 70 lb. for the first charge, and 5 lb. to 10 lb. less each time they are refilled, in order that the flux-line, the level of the surface of the liquid steel, where the chief corrosion of the pot takes place, may not come twice at the same height. When pots of plumbago or black-lead ware are used, they are frequently made to hold

75 lb. Clay pots stand from two to four rounds, depending on the fusibility of the steel melted, and black-lead pots about twice as many. Black-lead pots are, however, seldom used, except in melting the very mildest qualities of steel, such as the boiler-plate metal, for which Pittsburgh has acquired a deserved celebrity; steel so refractory that the best clay pots will soften and burst at a heat little greater than that required to render the steel liquid.

Three charges or rounds are melted in twelve hours, and generally the melting is carried on by day only, as the wear of the furnaces is much increased by working them day and night. The consumption of coke is from 2¾ to 3½ tons, a ton of steel melted, equivalent to from 4 to 5 tons of coal.

The preparations for melting the steel are commenced by making a coal fire upon the grate adjoining the annealing grate. The annealing grate must be large enough to hold twice as many pots as there are melting holes in the furnace. If that number be ten, twenty pots are put inverted upon the annealing grate, and the fire put down the spaces between them, which are then to be filled up, so as to cover the pot with the small coke riddled from among the coke used for melting, and upon these again the pot-lids are laid. This is done in order to have the pots gently heated to a red heat, ready for using. Each pot requires a stand and a lid. In form, the stand is the frustum of a cone about 3 in. high; and as upon the base of the stand the pot is to rest, they should correspond in size. The stand is made of common fireclay, but the lid of clay the same as the pot; it should be a little larger in diameter, flat on the under side, and a little convex on the upper. Each furnace has two stands placed in the proper position upon the grate bars; and upon the stands two pots, covered with their lids, from the annealing grate. Some fire, with a little coal, and soon after some coke, is put on; and when this has burnt up, sufficient coke to cover the pots; when the furnace and pots are at a white heat, the steel may be put in. The steel, having been broken and selected for the intended purpose, weighing say 34 lb. for each pot, is put into pans of iron or upon steel plates. To charge a pot, the lid is taken off, and the lower end of a conical-shaped charger placed over the pot, down which the steel is gently slid. The lid is then replaced, and the other pot being charged in the same manner, the furnace is filled with coke, and covered. Afterwards more coke is added, the quantity being determined by the experience of the steel maker.

Four hours will finish the heat, when a man removes the crucible, by means of basket tongs, from the fire, and puts it on the floor. Another workman takes the pot and pours the metal into the mould. Meanwhile the furnace is cleared of clinkers and made ready to receive the hot pot when emptied into the mould.

Brass Founding.—In a brass foundry of moderate size, it is very usual for the moulding and casting shop to be all in one. This does tolerably well where only small work is on hand; but where as many as a dozen moulders are employed, it will generally be found advantageous to separate the shops, in which case the floors should not be on the same level; the casting shop floor should be 2 or 3 ft. above that of the moulding shop. By this arrangement the men are enabled to move the flasks from the benches to the floor of the casting shop without stooping. The moulders pass the flasks into the casting shop, through openings in the partitions which divide the two shops. The moulding shop should therefore be narrow, so as to give the men but a short distance to carry the flasks, from the benches to the casting shop floor. There should be ample light, it should come from overhead, and over the benches if possible. These are generally placed along the whole length of the shop, or they may be arranged at right angles to the wall, two being placed back to back.

The sand heap should be centrally placed in the shop, with a shoot from the outside. The drying stove and core stove are in the moulding shop. These are heated by fuel, or by means of steam jackets, the latter plan being much the more cleanly and convenient. There should be a water tap and sink in this shop. The casting shop should be of the same length as the moulding shop, the furnaces being arranged on the opposite side to the moulding shop. This shop must be well ventilated; it should have openings at the floor level, and also in the roof, so as to keep up a current of air. Stores for coke and for ashes must be provided, and near the spot where the boxes are poured. There should be gratings over which the boxes are to be emptied, the sand going back to the moulding shop by an inclined plane. The dressing room must be next to the casting shop, so that all castings can be quickly passed in, weighed, cleaned, and dressed before being sent to the warehouse, which should also be near by. A bench, a few vices, and small tools are all that is required in the dressing room. The finishing shop should be a large, well-lit, and well-ventilated room adjoining the dipping and colouring rooms. These latter must be well supplied with water and sinks, and the north light is considered most suitable for them. The lacquering room must have openings into the finishing shop, and into the warehouse if possible. It must be kept quite free from smoke and dust, be well ventilated, and have a north light.

Modelling and pattern making are both used for brass work, and although these are distinct branches of trade from founding, where work is systematically performed, yet in small country towns there are many workshops where it is of great importance that the same man should be able to execute work and understand the general principles both of modelling and pattern making, as well as of brass founding.

The materials commonly employed for modelling are pipeclay and stucco. The former is used for work of a protracted nature, the latter for straight flat models, which can be finished off at once. Pipeclay, which is decomposed felspar, is made into a putty with water or glycerine; the glycerine prevents its getting hard for a considerable time.

Almost the only tools required for modelling are made of boxwood, with variously shaped ends. The handles are about 6 in. long; the sharpest edges are slightly nicked; the others are all more or less blunt. A horizontal lathe or turning table, like a potter's wheel, is also used for circular pieces. A few nicely planed boards, of various sizes, are required. On these boards an outline of scroll or other work required is drawn, the clay being placed thereon and modelled.

Clay is modelled with the hand and wood tools, mostly by pressure. The clay adheres to wood, or the turning table, when slightly moistened, and requires no other fixing.

Models, made either in clay or wood, and which are intended for immediate use, require to be made larger than the size given, by $\frac{1}{8}$ in. to every foot. Brass castings, under 12 in. in size, shrink about $\frac{1}{8}$ in. to a foot in the mould. Large castings shrink about $\frac{3}{16}$ in. For this purpose it is best to construct a measure or rule properly divided, so as to save time and calculation.

Should it be required, however, to make a metal pattern from the clay or wood, then the shrinkage will be double, and the model will require to be made $\frac{1}{4}$ in. larger, a foot every way, a second measure or rule being required. The real shrinkage is only $\frac{3}{16}$ths, but the other $\frac{1}{16}$th is allowed for finishing. Patterns exactly rectangular do not draw well from the sand; hence all patterns should be made with a taper of at least $\frac{1}{8}$ in. to every foot. Sharp internal angles should be avoided, as they leave an arris on the sand, which requires mending.

It is often necessary, in model making, to take impressions and casts from existing works, which cannot be cut up. In such a case an impression can be taken from it in guttapercha. To soften the guttapercha, either warm it in front of a fire, or place it in hot water, and knead it with the hands to make it of a uniform degree of pliability. After taking the impression, place it in cold water, otherwise the guttapercha will contract on cooling. Stucco is also used for this purpose, or a mixture consisting of four parts black resin, one part yellow wax.

For complicated patterns, or where cores are required, melt twelve parts glue, to which add three parts treacle.

Mouldings, and the like, can be quickly modelled in long lengths, by sweeping them up in stucco, or other material, by means of a board cut to the required profile, as is done in loam moulding. A moulding tub is employed for small brass work; it must be very strong, constructed of wood, provided with sliding bars, and a number of 1-in. boards with cross-ends the size of the moulding boxes.

The moulding boxes are similar to those already described, but usually smaller; wooden cramps, fastened by screws and nuts, being made to clasp these boxes lengthwise. In large boxes, cross bars are sometimes cast across them, or the bars may be of wrought iron cast in.

The details of pattern making, moulding, gates, runners, and other foundry details, have already been so fully described for iron, that it will be unnecessary to do more than briefly notice each process in the brass foundry, except where any material difference exists.

Ordinary plain work is arranged according to circumstances in the flask. When only one or two castings are required from a pattern, the pattern is wrapped into the flask, that is, the top part being rammed up, a portion of the sand is removed and the pattern inserted, or rapped in. After sprinkling on some parting sand, the drag is placed on, and facing sand sieved in, after which the ordinary sand is rammed in till the flask is full; then the flasks, top and drag, are turned over so that the drag is lowest, when the top part is taken off and emptied, the face of the drag cleaned again, and dusted with parting sand. After this, the top part is put on, and filled and rammed with facing and ordinary sand, as was done above. The top part is again removed, and the patterns withdrawn. In the process of parting the box and withdrawing the patterns it often occurs that part of the sand is torn away, which in consequence requires to be mended. This process of mending is a very tedious and costly one. When the moulds have been mended and finished, with gas and air outlets, and gates and runners for the inlet of the metal, the top and drag are put together, closed, and cramped. The mould is then ready to be poured. This mould is called a green-sand mould, not having been dried; but if a fine appearance is required, the mould before being closed should be placed in the drying stove. When a large number of any article is required, plate moulding, to which we have already referred at length, is very generally employed.

When an opening, or hollow, has to be left in the interior of a brass casting, a core is inserted in the mould. This consists, as usual, of a properly shaped piece of baked sand, exactly the counterpart of the hole that is desired; this is placed in the mould to prevent the metal or alloy from running into the space. To keep the core in its position it is made a little longer or wider than necessary, so as to have a bearing to rest on at each end. The pattern must have projections on it, so as to leave an impression in the sand to receive the end of the cores. Some cores have only one bearing, as in the case of undercut work, such as fluted columns and ornamental scrollwork. Innumerable modifications in the size and shape of cores exist in every-day practice, and much skill is required in their preparation.

Cores are usually made in boxes, Figs. 1317, 1318. Where it would be too costly to construct a core box, it may be dispensed with by moulding the pattern in sand, and casting it solid. A good composition for this purpose is one of plaster of Paris to two of brick-dust, mixed with water. When cast and dry, scrape down to the form of the core.

Cores, like moulds, must have passages in them to allow of the escape of gases, otherwise the casting will almost inevitably be spoilt. A wire must be inserted in the core to make such vent, and be withdrawn just before opening the core box to remove the core. When cores are large they are supported with iron rods, round which they are built up. To give consistency to the sand used in making cores, about one-half should be pure rock sand, which contains a certain amount of clay, but not generally enough, consequently the addition of clay water is necessary to give the sand cohesion.

The cores must be dried in a stove, at a temperature not exceeding about 400° Fahr. When dry they should be blackwashed, or coated with a mixture of ground charcoal and water, with a little size; this wash must be dried on in the stove, when they are ready for use.

In green-sand moulds it is advisable not to insert the cores till just before pouring, so as to prevent their absorbing moisture.

When a thin brass casting is required, the upper half of the mould is moulded from the opposite impression, and a thin packing piece of clay or other material is placed between the two boxes to keep them the required distance apart. When it is desired to mould small animals, butterflies, leaves, or other delicate and intricate objects which can be consumed by fire, they are suspended in a box, surrounded with a mixture of two of brick-dust to one of plaster of Paris, mixed with water.

This mould is placed in a furnace to consume the pattern, the remains being shaken out as far as possible, and the metal poured.

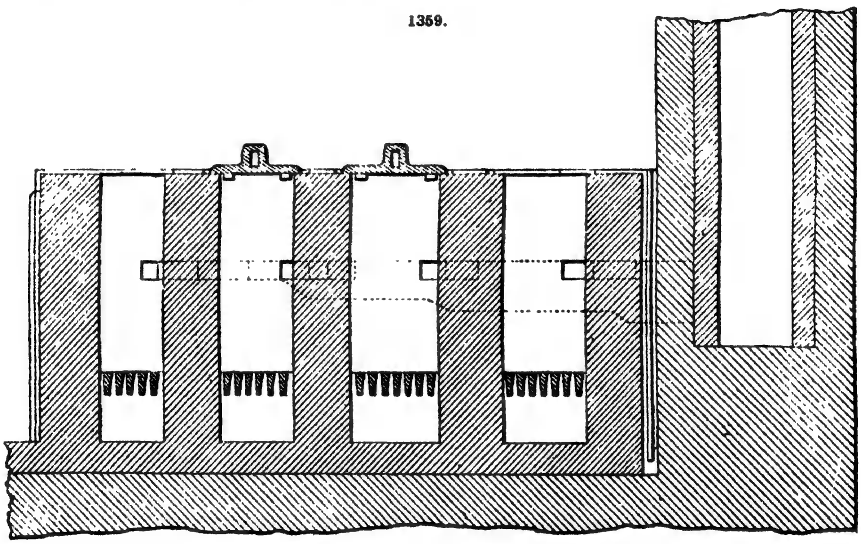
The air crucible furnace is that in which brass is usually melted, but when large castings are made, as those required for marine-engine work, or for ecclesiastical furniture, a reverberatory furnace will be found most suitable.

Brassfounders' air furnaces are most frequently sunk below the floor level, the ash pit being closed with a hinged iron grating. The covers for the furnace top may be either of cast or wrought iron, and should be of a dome shape; there should be a damper in the flue. The interior of the furnace must be lined with firebricks set in fireclay.

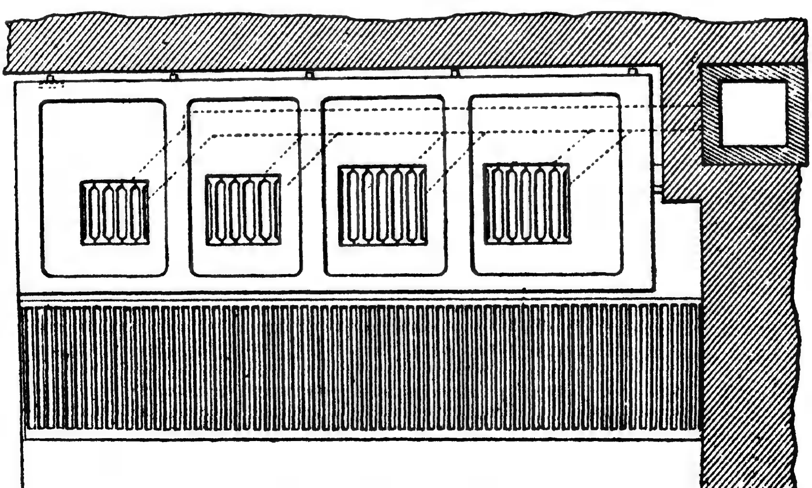
The crucibles used are either made of black-lead or Stourbridge clay. The latter are cheaper, but less durable than the black-lead, and require to be carefully hardened by a gradual exposure to high temperatures.

In mixing and pouring brass the least volatile metal should be melted first, the others being plunged under the molten metal with tongs, in small lumps, which must be hot and *quite dry*. The reason that the metal should be hot is that it may remain dry after being dried, as the steam from any slight moisture on it when placed in the melting pot would probably send the molten metal spirting about in all directions.

1359.



1360.

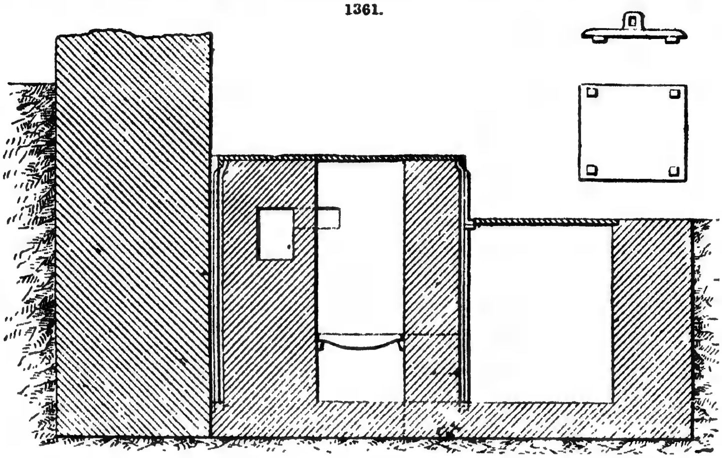


Figs. 1359 to 1362 represent an ordinary melting furnace, but in large works this arrangement is somewhat modified, the ordinary opening to the ash pit is stopped up, and fan-blast is admitted under the furnace bars; the mouth of the furnace stands about 8 or 10 in. above the floor.

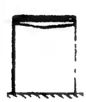
The fire bars should be so arranged, that on moving the front bearer a little forward, the front end of the bars will drop down, so that the furnace can be easily and quickly cleared from ashes and clinkers.

The fuel for the brass furnace is hard coke, which is broken up into lumps the size of a man's fist. The crucible is placed bottom upwards in the fire, so as to get it thoroughly heated; it is then removed with the tongs, turned right side up, and bedded on a slab of fireclay or firebrick, covered

1361.



1362.



over with its lid, and the fire neatly banked up around it. The metal is then placed in the crucible, the cover put on the mouth of the furnace, and the damper is opened to increase the draught; the crucible then remains until the metal is down. It is usual to throw in with the metal some charcoal dust or broken glass, which floats on the surface of the molten metal, and prevents oxidation. In feeding the metal into the crucible, put the copper or old brass in small pieces until it is nearly full. When this is well melted, add the tin, and mix it well in; then throw in a few small pieces of zinc. If the zinc flares up, throw the rest of it into the pot, stirring it in well; then lift the pot from the furnace, skim off the dross, and pour into the mould.

When placing the zinc in the crucible, drop a piece of borax as large as a walnut into it, this is done to prevent the loss of zinc which goes off in the fumes. If the surface of the hot metal is covered by fine charcoal or borax, which is prevented from burning, by being renewed, or by broken glass, the loss of zinc is reduced to a minimum.

If, however, when the small trial pieces of zinc are thrown in, they do not flare up, throw on a little coal to make the fire brisk, and cover it over till it comes to a proper heat. Then, as soon as the zinc begins to flare, add the rest. If old brass alone is melted, no tin is required, but a small quantity of zinc. If part copper and part brass, add tin and zinc in proportion to the new copper, with a little extra zinc for the brass. To prevent volatilization, charcoal, or broken glass, may be spread over the metal whilst being melted. If the metal is poured too hot the casting will be sand burned, and its colour impaired. The best castings are obtained when the metal is at such a temperature that it will cool quickly. Heavy castings should, therefore, be poured last. The metal must be carefully skimmed. Small work is poured vertically, large work horizontally.

As soon as the brass is poured, it is usual to open the boxes, and to sprinkle the castings with water from the rose of a watering pot, which makes the castings softer than they would otherwise be. When the casting is completed, let the fire bars drop, clear the furnace from ashes and clinkers, and place the pot amongst them to cool gradually. In a well-arranged foundry, when work requiring

a good supply of metal is undertaken, there are generally three or four such furnaces standing in a row, each having a separate flue leading to the chimney, which varies from 20 to 40 ft. in height, the more lofty it is, the better the draught. Each furnace has a damper to regulate its fire. In order to ensure constant work, it is quite necessary to have several furnaces, to allow of the necessary repairs to the lining, or other parts, being effected to one or other of the furnaces, whilst the remainder are in operation. The lining quickly burns away, and when the space around the crucible becomes larger than 2 or 3 in., a waste of fuel ensues. Road scrapings are often used for the lining, these contain silica and alumina; or refuse sand from glass grinders, containing flint glass, may be employed. The lining, mixed with water, is laid on like cement, and a brisk fire is at once started in the furnace, which glazes the lining.

The usual charge for a furnace of this description is from 50 to 60 lb., but of course, when several furnaces can be set to work, a casting of greater weight can be obtained. When, however, a casting of more than 2 cwt. is required, it is preferable on the score of economy to melt in a reverberatory furnace, as is done when statues, bells, and works of large dimensions have to be cast.

For small work the gas blast furnace is extremely convenient and economical, it is also very clean in working, and can be placed on an ordinary workshop bench. The cover and pipe over the crucible must be of fireclay, as the most intense heat can be obtained by this handy little contrivance.

Crucible tongs of various sizes are employed; they should be strong and well pinned together, so as to hold the crucible firmly.

Drying stoves for brass, when large, do not differ from those described at p. 661; when small, they consist of small chambers made of sheet iron. These can either be heated by a fire inside, or, what is much better, by steam jackets heated with the exhaust steam from the engine.

Bronze fine-art work has for a long period been skilfully practised in France, and both for design and execution the results obtained by French artists and founders are still unequalled, it is scarcely too much to say they are unapproached. During the reign of Louis XIV., alloys of 91·3 copper, 1 to 2 tin, 5 to 6 zinc, and 1 to 1·5 lead, were used. Another mixture employed was 82·4 copper, 10·3 zinc, 4 tin, 3·2 lead.

In a fine-art foundry, if the works generally to be produced are small in size, the moulding is done on benches, and the moulders work *vis-à-vis* at the same bench, which is divided by a longitudinal partition, provided with a shelf for tools. Small and unimportant pieces may be moulded in green sand, large works in loam, but the greater portion of general work is moulded in dry sand. The sands are mixed in proportions carefully regulated according to the nature of the work for which they are intended, and the mixture is reduced to a uniform fineness by being passed between cast-iron rollers. The sand is then damped and sifted. The moulding boxes are of cast iron, accurately fitted, the edges being planed true. When the objects are to be finished in the lathe the patterns are sometimes of wood, but most frequently bronze models are made, and are truly finished to the desired form. Many other substances are used for models, such as plaster, wax, fusible metal, porcelain, and glass.

For facing sand a mixture of potato starch and charcoal dust, or fine white flour, is used; but charcoal dust is the favourite material.

Sand cores are used for all hollow pieces, unless these are to be cast in loam, or are of a large size; in the latter case the cores are of loam. In bronze statue casting, the thickness of the metal should be as nearly uniform as possible, otherwise work will be distorted from unequal contraction; bronze contracts considerably on cooling, the extent depends upon the proportions of the constituent metals employed in its composition, and varies from 1 to 2 per cent. This contraction is found to increase in ratios with the size of the casting.

The perfection of bronze work is said to consist in having the mould very highly finished, and obtaining a bright sharp casting, which shall require only a minimum amount of subsequent chasing and tool-work, thus leaving the skin of the casting as far as possible undisturbed.

Best English or Straits tin, and very pure South American copper, which latter is purified by liquation, are the metals employed. A proportion of gates and runners may be added, but this is only done when the proportions and quality of their ingredients are known, and no old bronze guns, old copper or brass, or other material of unknown and variable composition, should be used, as it is considered impossible to rely upon obtaining a first-rate casting from such uncertain ingredients.

The moulds are placed in cast-iron boxes, which are placed in a naked pit. A reservoir formed of sand with a charcoal facing is employed, into which the contents of the crucibles or air furnaces are drawn. This reservoir communicates with the main gate of the mould, and as soon as a sufficient quantity of metal is in the reservoir, an iron plug in the bottom is removed, and the metal flows into the mould, from whence the surplus passes off by rising heads, which are purposely kept small for fear of distorting the casting from too great a pressure. The gas evolved during the pouring is fired at the rising heads by a torch.

Bronzes which are intended to be coated with enamel, have their surfaces specially prepared for its reception, by *cloisonné*, or partition, work. This process is a somewhat tedious one, and requires great skill on the part of the moulder. The outlines of the design for the enamel are described by small thin partitions of bronze, projecting upwards from the main body of the work less than a twenty-fifth part of an inch. Thus the bronze has its surface covered with a network of fine lines, and when the enamel is baked into the shallow cells so formed, the enamel and the bronze partitions are ground and polished to a uniform depth. These partitions serve two useful purposes, they describe the outlines, and they tend to hold the enamel firmly in position.

In finishing patterns for this class of work, every irregularity in the cells and partition walls has to be cut out, and great care is necessary not to injure the surface.

When such patterns are finished, they represent a considerable value in skilled labour, and are extremely delicate, consequently they are kept covered up on soft cushions, away from danger of accidental damage.

The founding of statues is a very ancient branch of the art, and among early methods, the most familiar is known as the cire-perdu, or waste-wax process, which was still in vogue when the present system was introduced, and a comparison between the two will best illustrate the progress now accomplished. The cire-perdu process required great care, and could only be carried out effectively by the sculptor or modeller himself. Thus let us suppose, for the sake of simplicity, that the object to be reduced is a portrait bust measuring 4 in. in height and 3 in width. The first step would be to model in sand, or a mixture of porous cement, the outline of the bust, taking care to make it on every side $\frac{1}{4}$ in. smaller than the size it was designed to give to the finished statuette. This core must be coated up with wax to make up the deficient $\frac{1}{4}$ in. This much might be accomplished by an ordinary workman, but for the rest the services of the artist are indispensable. With great delicacy of touch he must work up the likeness and texture of his subject on the wax.

The portrait completed, five or six pieces of wire must be pushed through the wax into the sand outline or core. It is now necessary to coat over the wax with liquid sand, applied most carefully with a fine hair-brush. When a few coats of this sand have been made to adhere to the wax, the statuette is surrounded by an iron frame, and the frame is filled up with sand mixture. The frame is generally about twice the size of the statue. When all is ready, this frame is removed with its contents to a warm place, so that the water may evaporate from the sand and the latter gradually consolidate. Holes must then be cut at one end through the outer sand casing to the wax, after which the frame is baked in a hot oven. The wax melts and runs out of the small perforation, leaving a space between the inner core, maintained in its position by the wires, and the outer mould, which latter bears the faithful impression of the modelling bestowed on the wax. The holes through which the wax escaped are now used for the purpose of introducing the molten bronze.

The method now pursued is more scientific, and involves piece-moulding. Taking a small section of the statue, the workman forces the sand by striking it gently with a mallet into every fissure and crevice of a plaster model imbedded in sand, and thus obtains an accurate impression of that part of the model on which he has been working. Having completed one piece, he proceeds with another, till, by putting the pieces together, he can cover that part of the statue which is exposed out of the sand box. The model is then lifted from its bed, turned round, impressions taken of the other side, and when this is completed the model can be removed uninjured.

The pieces of sections of the sand having the impressions of the model are fitted together in their relative seatings within the two halves of the mould box. A core is made in the impress a little smaller in size, so that when this is placed within the mould, there should remain all round a margin between the mould and the core equal to about $\frac{3}{16}$ in. in thickness. The core and the pieces which constitute the mould being secured in their respective places, the whole is then stoved. Vents for the foul air and gas must also be provided, and runners to enable the metal to penetrate rapidly the margin between the core and outer mould, after the bronze has thus been cast. Owing to the intricacy and fineness of the model, it sometimes requires a great number of pieces to make the mould, and several months' work to finish successfully, even a group small enough to be stood upon a mantelpiece. One of the great advantages of this new process is the fact, that if the casting fails, the artist's chalk model, the result perhaps of infinite labour and of an inspiration which may never be repeated, remains unaltered. A new mould may be taken from it, and the second cast prove a success. The statue may thus also be reproduced as often as desired; while with the old process the artist's work was carried away for ever as the wax melted, and if the cast proved a failure, there was no longer any record remaining of the work done and lost.

Small bells are generally moulded in sand from a metal or wooden pattern, and the sand mould is dried in a stove. Having before described such moulding, it will not be necessary to enlarge here upon the casting of small bells, of less weight than, say, 112 lb. The most important point in the art of bell founding is the proper form to give a bell to obtain the desired tone, which is also dependent upon the metal used.

Large bells are moulded in loam, in the same way as the large pan, Fig. 1319. The core is built in brick on an iron platform, which must have snugs in case the mould is made above ground. This brick core is covered with $\frac{3}{4}$ in. or 1 in. thick of hair loam, and the last surface washing is given by a finely ground composition of clay and brick-dust. This latter is mixed with an extract of horse-dung, to which is added a little sal-ammoniac. Upon the core the thickness is laid in loam sand, but the thickness is again washed with fine clay to give it a smooth surface. Ornaments which have been previously moulded, either in wax, wood, or metal, are now attached by means of wax, glue, or any other kind of cement. If the ornaments are of such a nature as to prevent the lifting of the cope without them, for the cope cannot be divided, the ornaments are fastened to the thickness by tallow, or a mixture of tallow and wax. A little heat given to the mould will melt the tallow, after which the ornaments adhere to the cope, from which they may be removed when the cope is lifted off the core. The thickness must be well polished; and, as no coal can be used for parting, the whole is slightly dusted over with wood ashes. The parting between the core and the thickness is also made with ashes. The cope is laid on at first by means of a paint-brush, the paint consisting of clay and ground bricks, made thin by horse water. This coating is to be thin and fine; upon it hair loam, and finally straw loam is laid.

The crown of the bell is moulded over a wood pattern, after the spindle is removed. The iron or steel staple for the hammer is set in the core, into the hollow left by the spindle. It projects into the thickness, so as to be cast into the metal. The facings of the mould ought to be finished when the cope is lifted off. Small defects may occur, and are, if not too large, left as they are; the excess of metal in those places is chiselled off after the bell is cast. All that can be done in polishing the facing of the mould is to give it a uniform dusting of ashes. When the mould is perfectly dry, it is put together for casting. The core may be filled with sand, if preferred, but there is no harm done if it is left open; for bell metal does not generate much gas, and there is no danger of an explosion. The cope is in some measure secured by iron, but its chief security is in the strong,

well-rammed sand of the pit. The cast-gate is on the top of the bell, either on the crown, or, if the latter is ornamented, on one side of it. Flow gates are of no use here, the metal must be clean before it enters the mould: there is no danger of sullage.

Another plan is to make the cope of iron larger than would fit the bell; this is lined with loam, turned true by means of an inside instead of an outside sweep, and the junction being between an iron plate at the bottom of the core, and the flange at the bottom of the cope, they can be fitted together more accurately than the clay core and cope could be, and, moreover, bolted together, so as to resist the bursting pressure of the melted metal, instead of having to rely merely on the sand with which the pit is filled, and such weights as may be placed upon it. The core and cope are both made very hot before the pit is closed in with sand; for that is necessary to prevent too rapid cooling, which makes bell metal soft, indeed, if the cooling is very rapid, it will make the metal malleable.

The mode employed in casting a large bell in England is thus described: The metal was twice melted; it was first run into ingots of bell metal in a common furnace, and then these ingots were melted and run into the mould from a reverberatory furnace. The ingots were only in the reverberatory furnace two and a half hours before the metal was ready for running, and the whole 16 tons were run into the mould in five minutes, quick running being considered essential for the production of a sound casting.

Cleaning and Dressing Castings.—The casting in foundries is generally performed in the afternoon, so as to make it the last business of the day. This time is chiefly selected to escape the heat of the hot sand after casting, which will then cool during the night. After casting, the castings are removed, and the moulding boxes piled in a corner of the building, so as to be handy for the next day's work; water is sprinkled over the sand, it is then shovelled over, mixed, and thrown in heaps, where it remains during the night. If the latter work has been properly performed, the sand will be of a proper and uniform dampness the next morning. Each moulder takes charge of his own sand, and but little practice is required to learn the proper amount of water to be used in damping the sand.

When the metal of a cast is so far cooled as to be strong enough to bear removal, the moulds are taken apart, and the sand or loam is removed from the casting. Small castings require but a few minutes to cool, while heavier casts take hours and even days. A massive casting, such as a forge-hammer of 5 tons weight, will take twenty-four hours cooling in a green, and forty-eight hours in a dry mould. The excrescences, fins, spurs, and all ragged edges, which may happen to have been formed in the partings of core joints, are broken off as soon as the cast is removed from the mould. The gates are, at the same time, broken off by the moulder; it requires some degree of skill to break a gate off smooth. Heavy castings are chained to a crane and hoisted by it. Very heavy castings require the united strength of two or more cranes. Small castings are removed from their moulds by tongs; one, two, or more persons taking hold of a casting at the same time, carry it to a place termed the fettling shop, designed for the reception of hot castings. Projections which cannot be removed in the foundry, are chiselled and chipped off in the yard, or in the fettling shop where the casting is roughly prepared for further work. Heavy cores, and particularly hard cores, are removed in the foundry before the casting is entirely cold.

The cleansing of castings is a simple operation in an iron foundry where common castings are made. The first is done by means of chisels or sharp hammers; the latter, with dull, coarse files, which have been used or rejected by machinists. Cast-iron files are also used for the latter purpose. The trimming and cleansing of valuable castings is generally entrusted to skilled workmen, and on such articles as statues, the artist himself generally works out the details of the more important points.

Grindstones are largely used in fettling. They should be of a hard, close-grained, sharp quality, free from veins, and uniform in colour. The stones are generally driven by steam-power.

Neither files or grindstones, however, fettle so well as emery wheels, which are formed of emery of requisite coarseness, mixed with a cementing material.

Small blocks of consolidated emery may be used with great advantage by hand; but the proper result is obtained when the form of a circular disk is adopted, and the same rotated at a high speed.

See Cast Iron, Fans, Lifts, Hoists, and Elevators.

GAS, MANUFACTURE OF.

The manufacture of gas being based upon the distillation of coal, it may be well to commence the consideration of the subject by briefly classifying the coals employed. Lignite or brown coal has but small interest for the gas manufacturer, but a variety of lignite which nearly approaches the bituminous caking coals in composition, and termed pitch coal, is of somewhat small value to the gas producer. Caking coal, found in almost all the coalfields of Great Britain, but chiefly in the Newcastle and Wigan districts, is the chief material from which gas is produced. Cherry or soft coal, sometimes termed peacock coal, is similar to caking, but does not fuse when heated. Splint or hard coal, chiefly used in metal making, smelting operations, is largely employed for the reason that it yields an excellent coke. Cannel coal has been largely used for the manufacture of gas, but the manufacture from this coal only has not been attended with commercial success.

As to the gas-producing power of the various coals, the amount of illuminating gas and the illuminating power depends chiefly on the proportion of hydrogen contained in the coal. The state of combination of the hydrogen may be said to be unknown, except that under the influence of heat the compound breaks up and recombines to form the gaseous combination of carbon and hydrogen to which the luminosity of the gas flame is due. There is always a residue of free hydrogen. Cannel coal owes its value to the fact that it contains from 6 to 10 per cent. of hydrogen. The oxygen contained in the coal must have some influence upon its illuminating quality, since it influences the quantity of the known illuminating gas carbonic oxide and that of carbonic acid. Oxygen also

determines the production of oxygenated compounds in the tar, such as carbolic and cresylic acids. The gas-producing power of a coal can only be satisfactorily ascertained by trial on a working scale, although experiments on a small scale will yield a result sufficiently approximate to accuracy for practical purposes. These testing apparatus are generally miniature gasworks, in which about 5 lb. of coal are operated upon at a charge. Bower's apparatus, which it is unnecessary to illustrate, consists of a vertical retort fixed in an iron case, complete in itself without brickwork, beyond that required for lining and protecting the case. The casing is fitted with two furnace doors and frames in the cast-iron top plate. The retort, supported by a flange resting on the top plate of the casing, is fitted with a vertical mouth-piece and cover, removable for charging, and a side outlet for gas and other products of distillation. The retort is made conical in shape, fixed with the larger diameter downwards, so that the coke may readily leave the retort when the cover and disc plate has been removed, which is easily effected by a hand lever. The bottom lid or discharging door is fitted with a projecting disc plate, made to enter the retort so far as to receive the charge of coal above the fire bars, where the retort obtains proper heat. The apparatus for purifying the gas produced contains in one vessel the hydraulic main from the retort, the condenser, and purifier, and the apparatus is completed by a self-sustaining gas-holder, 5 ft. in diameter by 2 ft. 6 in. in height, containing 50 cub. ft. Sugg employs a somewhat similar apparatus, in which the retort is capable of carbonizing 2·24 lb., or the $\frac{1}{1000}$th part of a ton of coal; in some applications of this testing apparatus the case holder would become of inconvenient size but for an arrangement, devised by W. Mann, of meters of equal size fixed one on the top of the other, the drum shaft of each being connected in such a manner that one drum cannot revolve without the other. At the back the inlets of both meters are connected to the same pipe. The outlet in the lower meter is conducted to a float of lights, and that from the upper meter led directly to the gas-holder. The capacity of the meters being equal, one-half of the gas passing from the retort is led away to the float and consumed, while the other half goes to the gas-holder and is stored for further trial. When coal is carbonized at a temperature of 600°, a temperature at which the heat is only just visible in a dark room as a faint red, these volatile parts are nearly all converted into liquids as tar or oil and water, with the evolution of only a small quantity of gas, equivalent to a few hundred cubic feet a ton of coal, the coke remaining in the retort being of a soft friable character. By this process the oil or tar from boghead or other cannel coals, ashes, and bituminous substances is obtained, purified, and sold as paraffin oil. As the heat of the retorts is increased the quantity of gas is increased, and at a temperature of 980°, the yield from a ton of Newcastle coal is about 6000 ft. At this temperature there is no practical accumulation of carbon in the interior of the retorts, and only slight deposits of carburet of iron in their exterior even after a year's operation. When the temperature is further increased a larger volume of gas is obtained, the quality of the coke improved with a smaller yield of tar, and at 1400°, a quantity of 8000 cub. ft. a ton of Newcastle coal is produced. Between this temperature and 2000° the yield is increased, but the quality is somewhat lessened; about 2000°, or at a dull orange heat is probably the best for the production of gas and coke from caking coal. A higher degree of heat, while it produces harder and brighter coke, reduces the quality of the gas. Above 980° the olefiant gas is decomposed and its carbon deposited on the walls of the retorts. This deposit is nearly proportional to the diameter and pressure of gas within the retort, but by reducing the pressure by an exhauster or other means, the deposit, as far as that which is due to pressure is concerned, is removed, the residue being due to the effect of temperature.

Cannel as a rule is more easily distilled than caking coal, and gives off its gas in about one-sixth less time. With cannel the first hour of carbonization is usually the most productive, but in the carbonization of caking coal, the second hour is that during which the greatest amount of gas is generally produced, during the first hour the moisture converted into steam absorbs considerable heat, and condensable hydrocarbons are chiefly produced. When the final temperature is high the coke is a grey colour and is hard, but is always porous from the passage of the gas through it. The length of time required for extracting the whole of the gas from any ordinary charge of coal is controlled by the heat of the retort. Amongst gas engineers there is considerable difference of opinion as to the method of operation in carbonization, some prefer small charges of short duration, in this case the labour is proportionally increased, but excess of charges give a low production of gas; as a general rule, in closing the door of the retort the gas should issue with a vivid flame, if this is not the case the temperature of the retort is too low or the charge is too heavy. Gasworks properly constructed with a production of 2½ millions cub. ft. per annum, should sell 25 per cent. of the coke produced when making 20 millions cub. ft., 60 per cent. Many of the English companies sell 81 to 83 per cent. of the coke they produce.

To furnish sufficient temperature for carbonization a draught of air to the furnace is necessary, and if the flame issues from the sight holes of the retort setting, there is either an insufficient supply of air by the damper being too far closed or the lateral flue is stopped. If the whole of the beds are similarly affected the main flue may be blocked, or the shaft of insufficient capacity; the fire bars of the furnace should always be kept clear to allow the free passage of air to the fuel. When ordinary coke is used a slag or clinker requires removal about once in every twelve hours, and the bars should be cleared at intervals from beneath by a pricker. To economize fuel in the furnace a sufficient damper control is necessary to prevent waste from too great influx of air. Coals intended for gas-making should be kept from the rain. Cannel readily dries when placed before the furnace; the slack coal contains moisture for a long time. When coals are placed in the retort in a wet state, the steam produced not only absorbs heat, thus increasing the production of tar and lessening that of gas, but it adds to the sulphur impurities by its own decomposition in presence of protosulphuret of iron. To prevent loss of heat by radiation the retort house should not have too many openings, and all these with the exception of the doors should be above the level of the retort benches. The walls forming the backs of the settings and the end walls should be not less than 2 ft. thick, including the firebrick facings; the arches should be protected by 18 in. of common

brickwork on the top of the crown. The lateral and main flues should be enclosed on their tops and sides to a thickness of 14 in., than which the front walls of the settings should never be less. Sight boxes, which are only necessary for the observation of temperature, when used with clay retorts, should not be in excess; two for a bed of five retorts are sufficient and should be of 2½ in. or 3 in. diameter, their plugs being filled with fireclay. All beds when not in use and near retorts in operation should be bricked up, and the retorts have a 9-inch wall built within their mouths, the furnace bar and ash pan should be similarly closed, and the dampers fixed and luted with fireclay.

The first process of gas manufacture is the carbonization of the coal, which is effected, as has been described page 1610 of this Dictionary, in retorts. The bunch of retorts in large gasworks is usually placed in the middle of the retort house. The retorts are built in ovens or settings, and are generally preferred open throughout their length with mouth-pieces at both ends. The first process is the heating-up of the retorts, by furnaces, one at each end in front of the bench. These are charged, and the heat kept up with the residual coke after the coal has been carbonized.

Sometimes, but principally in cannel gasworks, a quantity of tar is introduced above the furnace to assist the coke; another way of applying tar is by running a slender stream in the centre of the bench. An air flue must be carried in the brickwork to the place of combustion, so that the tar may be properly consumed. Tar is, however, generally found superfluous for ordinary heats, and is only used when it is necessary to charge the retorts more frequently than every six hours. The flame and hot draught of the furnaces are caused to circulate throughout the setting, traversing as great a space as possible, round, under, and above the retorts before egress is allowed to the main flue. Evaporating chambers, where the wet lime, when foul, is run from the purifiers, are usually built in connection with the main flue, and the heat thus utilized to reduce the lime to a pulpy mass, used for luting the retort lids.

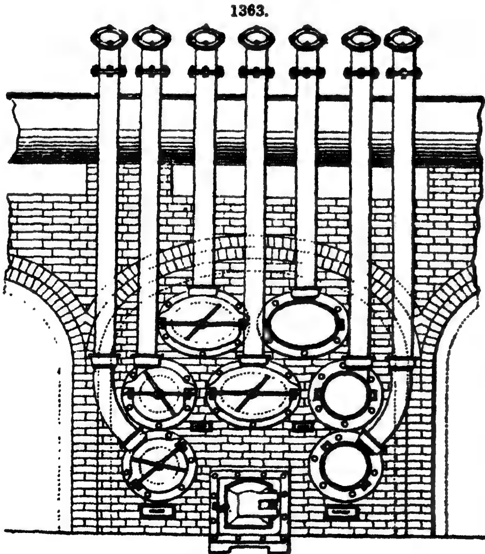
The retorts when sufficiently heated are charged at each end with a scoopful of bituminous coal, after which the lids are screwed up, and the process of distillation commences.

Light carburetted hydrogen, free hydrogen, ammonia, and other light gases, are rapidly evolved during the first hour of the charge; and, following these olefiant gases, mixed with some of the heavier impurities, gradually begin to rise towards the latter hours of the distillation. Carbonic acid, sulphur, and other heavy vapours, are freely given off, so that it is at all times false economy to protract the distillation beyond the ordinary period; the additional cost of purifying material and extra labour, besides depreciation in the quality of the gas, more than counterbalancing any extra quantity that may be obtained. To define the time for distillation is, however, practically impossible.

Seven retorts in a bed is the number stated to combine most profitably the saving of fuel with production of gas manufactured when using common bituminous coal. Figs. 1363 to 1365 are a front elevation, transverse section, and longitudinal section respectively, of such an arrangement. In cannel works three to five retorts are a maximum, but in these much higher heats are required; the retorts being charged oftener, the heats are more difficult to maintain.

The advantages of fireclay and iron as materials for retorts were long discussed among gas engineers, but fireclay gradually gained favour, and is almost universally adopted.

1363.



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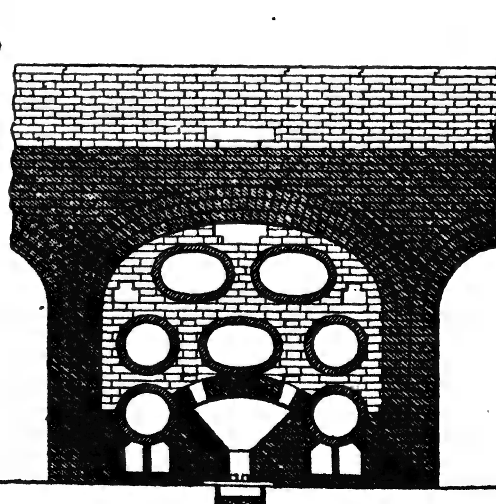


Round, flat D, and oval are the shapes employed, and each has its advocates.

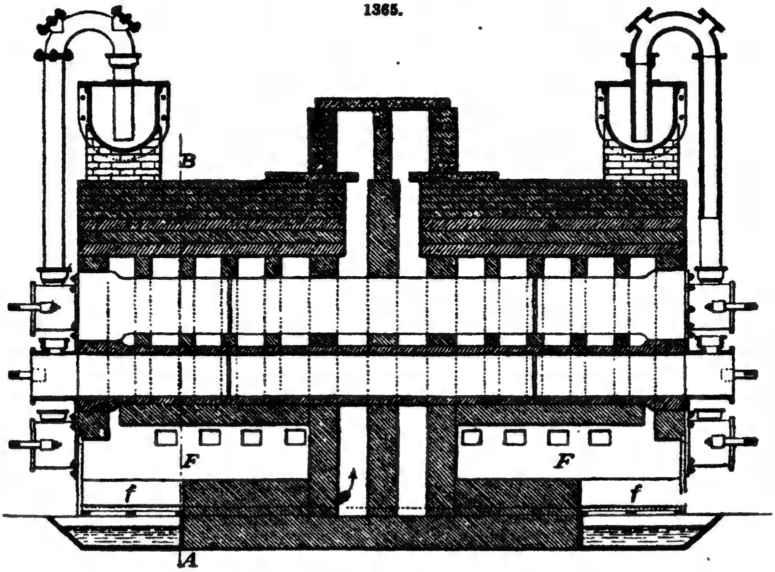
Flat D retorts have a more extensive and equal heating surface than the others, and on that account are supposed to produce a larger quantity of gas a ton of coals carbonized; but they are seldom found to expand and contract equally, and, however carefully protected, the corner next the furnace invariably succumbs to the fire.

Round retorts contract and expand equally, and are always found to be more durable, but if

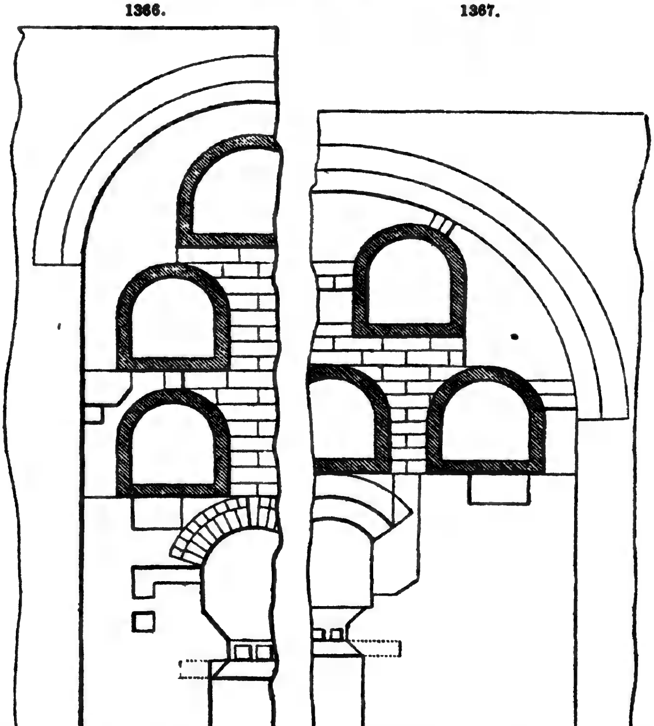
made of a large size do not give good results in carbonizing. They are generally, for convenience, set with others of the oval shape, and these having the advantage, from their form, of a larger heating surface, combined with the strength of an arch, and regularity in expansion and contraction, manufacture more gas a ton than the round, and are nearly as durable.

Clay retorts, when first heated, have a tendency to crack, caused partly by expansion, partly by

1365.



1366. 1367.

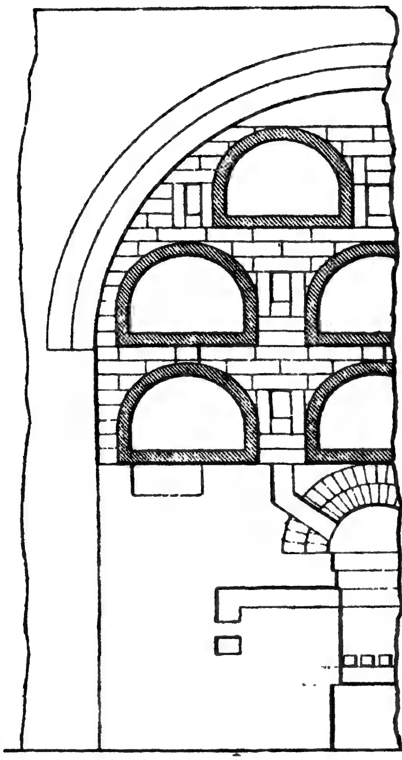


the expulsion of vapour from the clay. The effect of expansion cannot be avoided, but injury from the expulsion of moisture may be almost entirely prevented by a slow and careful process of heating, in which case the retorts will gradually acquire their intended colour without perceptible damage. Similar caution ought also to be exercised in cooling down when the oven is no longer required for

the season; contraction if allowed to take place too suddenly, being most destructive in its effects, and great care should therefore be taken by closing up every aperture by which air can gain admittance after the fires have been withdrawn, to sustain as long as possible the dead heat that is inside the bench.

Figs. 1365 to 1369 are sections of retort settings generally adopted. Fig. 1366 is the method of setting retorts at the Chartered Gasworks; Fig. 1364 the method at the Commercial Gasworks; Fig. 1369 at the Imperial Works, St. Pancras; Fig. 1367 at Gasworks at Valparaiso; Fig. 1368 at

1368.



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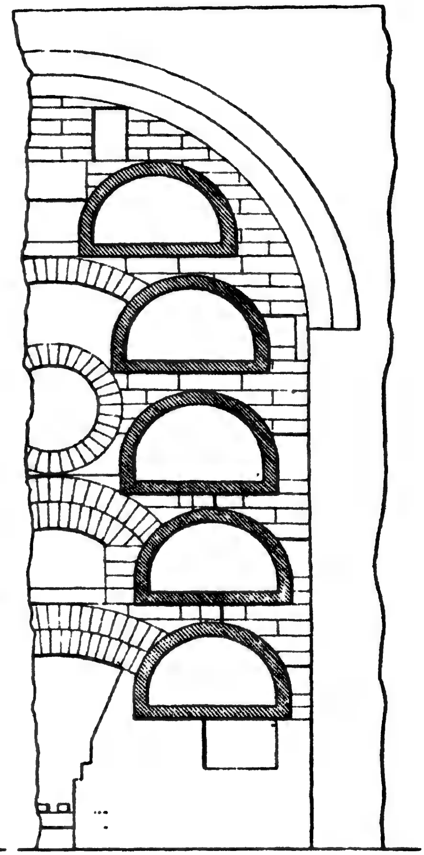
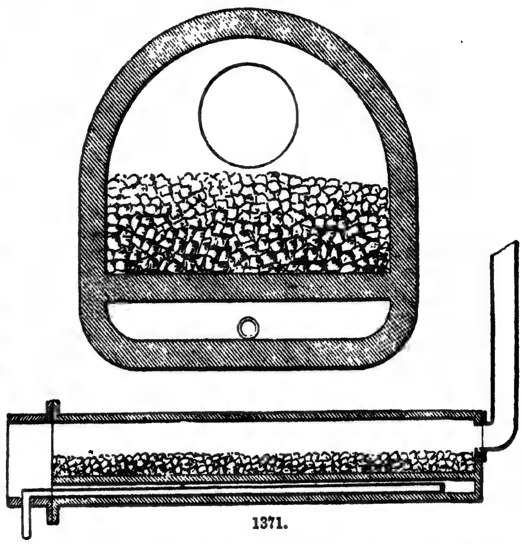


Westminster; and Figs. 1370, 1371, are of Henderson's superheated steam retort. The object of this latter arrangement is improving the quality of the gas by the decomposition of the tarry vapours. The retorts are of iron, cast with a double bottom, so as to leave a space of about $1\frac{1}{2}$ to 2 in. between the bottom on which coal and creosote are placed, and exposed to the fire. In this space an iron steam-pipe is placed, $\frac{3}{4}$ of an in. diameter, screwed into the bottom of the mouth-piece, and extending nearly to the back of the retort. A similar pipe is connected with the boiler of the steam engine, but placed in the upper part of the main flue, so as to be exposed to the waste heat from the retort furnaces; by this means the steam becomes highly heated before entering the retort. The steam on issuing from the open end of the pipe at the back of the retort, acquires additional heat, by passing over the surfaces of the bottom of the retort. On reaching the front it comes in contact with the vapours and gases generated from the mixture of coal and creosote, which are carried away by a pipe at the back of the retort. In large works, and with clay retorts, the system of through setting, with double mouth-pieces, is the most economical, both for fuel and durability. But this arrangement is open to objection. If the retorts are used for the generation of gas of high illuminating power, the increased surface over which the gas passes after it is eliminated from the coal, exposes it to the probability of decomposition, and the consequent deposition of its carbon. That this action occurs is observed from the amount of solid carbon, or graphite, found on the inner surface of the retorts. In through retorts this deposition is due to two causes; in charging the retort with coals, either by the scoop or shovel, the centre of the retort seldom receives the proper quantity of coal, and as this part is always the hottest, the gas generated from the thinner stratum of coal is exposed to intense heat, and is speedily decomposed, liberating the hydrogen and depositing the carbon. Another cause of this deposit is want of uniformity in the pressure in the two hydraulic mains; a slight resistance causes more gas to take the course offering least obstruction, and as the particles of gas thus pass over a larger amount of heated surface, they

are exposed to the greater risk of decomposition. Several expedients have been suggested as a remedy; one is to use a valve to each ascension pipe, so as to dispense with the dip-pipe when the retort is working; another is to have only one hydraulic main, placed over the centre of the ovens, and both mouth-pieces connected to it by a single dip-pipe.

The material of which the retort is made, will exert a very important influence on the production of gas of high illuminating power. The high temperature at which clay retorts are worked tends to produce a very large quantity of carbonic oxide and hydrogen, by the decomposition of the olifiant gas and hydrocarbon vapours. It is frequently asserted that by the use of richer cannel coals, the excess of non-illuminating gas is rendered highly luminous, by becoming saturated with the hydrocarbons given off from the richer coal; but this is only true to a limited extent, for the mixture undergoes rapid deterioration, consequent on the liquefaction of a large portion of these hydrocarbon vapours.

1370.



1371.

Retorts are now charged and discharged mechanically. In J. West's first arrangement, the charger, Fig. 1372, is a wrought-iron carriage running on wheels W. The carriage is partly open at the top T, and the bottom consists of a plate divided into a number of parts of equal width. Beneath the bottom there is a second sliding plate, having parts of the same width as those of the charger, so that according to the position of the sliding plate, the ports may be opened or closed. At the front of the charger, there is a coupling arm, for the attachment of a long rod. This arm is free to revolve, and has affixed to it a bevel wheel, gearing into a second bevel wheel, which is attached to a crank actuating the port slide. A half turn of the arm suffices to move the slide to

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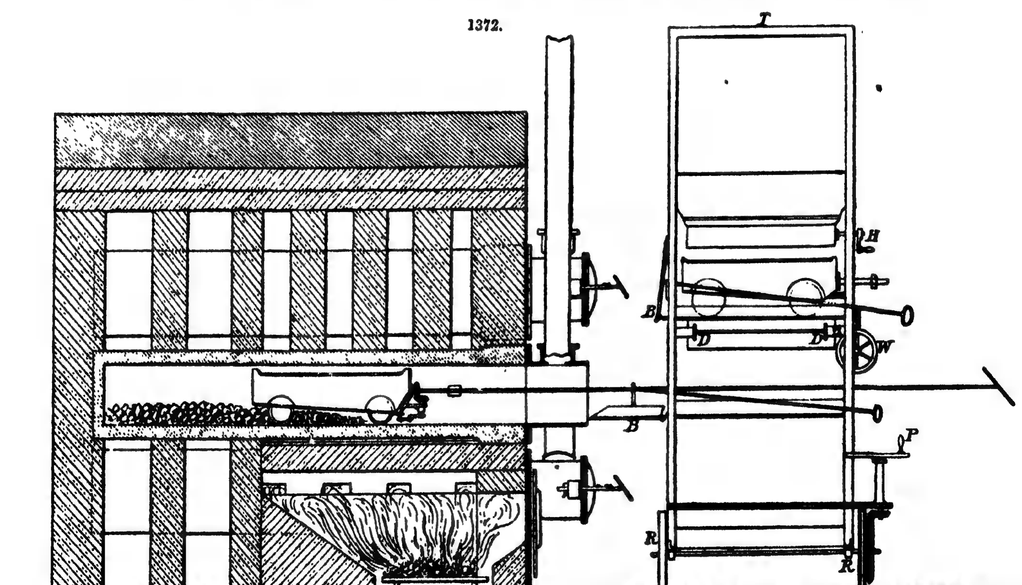


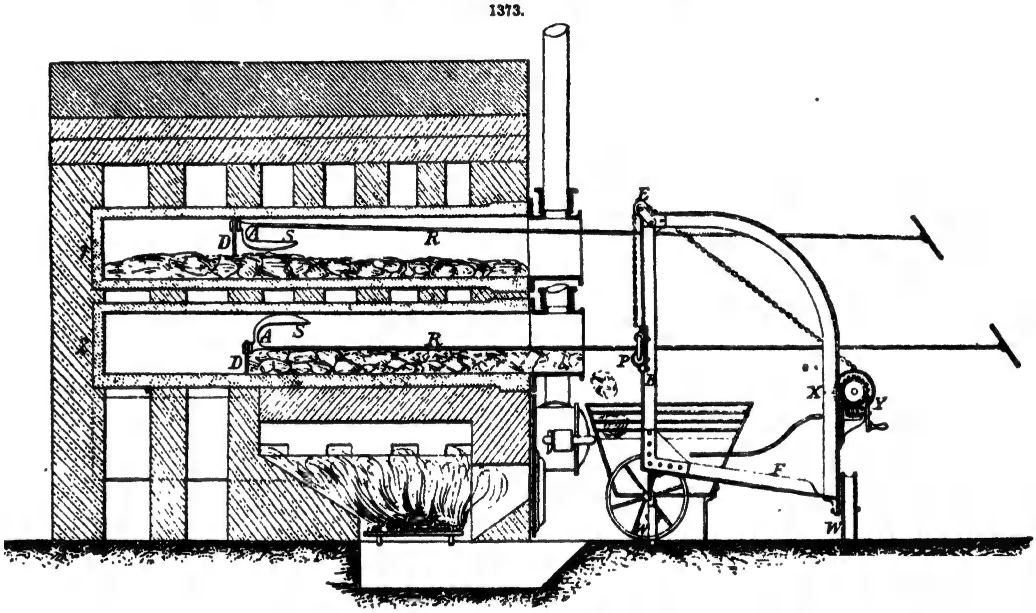
the required extent, to cover or to uncover the bottom ports of the charger. The wheels are serrated. The object of this is to secure a slight vibration of the charger when running, and the certain delivery of the coals. The mode of discharging has however been altered in more recent arrangements.

A trolly T, Fig. 1372, formed of a framework of wrought iron, with runners R, travels upon rails laid in front of the retort benches. This trolly carries a hopper, and sliding stage S, which may or may not be attached to each other, suspended by chains carried to a winding drum D, so as to be easily and expeditiously adjusted by the wheel W, to the height to suit retorts at different elevations. The bottom of the hopper terminates in a rectangular shoot of nearly the same length as the space T, at the top of the charger. This shoot is fitted with a four-bladed roller, the spindle of which projects through the end of the shoot, and is provided at H with a handle. The trolly is moved along the rails by turning the propelling wheel P, which rotates a pinion gearing into a spur wheel affixed to the shaft of two of the runners R. Attached to the back of the stage there is a drawbridge B, which spans the space between the stage and the retort mouth-piece, and is lowered or raised by a rod.

The charger being placed upon the sliding stage, and the latter adjusted to suit the elevation of the retorts to be charged, the handle H is turned a few times, and the coals fall from the hopper and fill the charger, to which has previously been attached a long rod with a cross handle. The bridge B is lowered, and the charger driven by one man to the back of the retort; a half turn is then given to the handle, and the bottom ports are opened, the charger is drawn forward, and by the time it reaches the mouth-piece will have deposited the coals it contained in an even layer about 3 in. in thickness upon the floor of the retort. When the charger reaches the stage, the bridge is raised, the trolly moved on to the next retort, and the operations are repeated.

Fig. 1373 is of West's apparatus for drawing retort charges. A curved arm is welded near to the end of the drawing rod, and to this is attached a kind of slipper S, so that when pushed into the retort the slipper takes an easy bearing on the coke. The rake consists of a semi-disc D, of

1373.

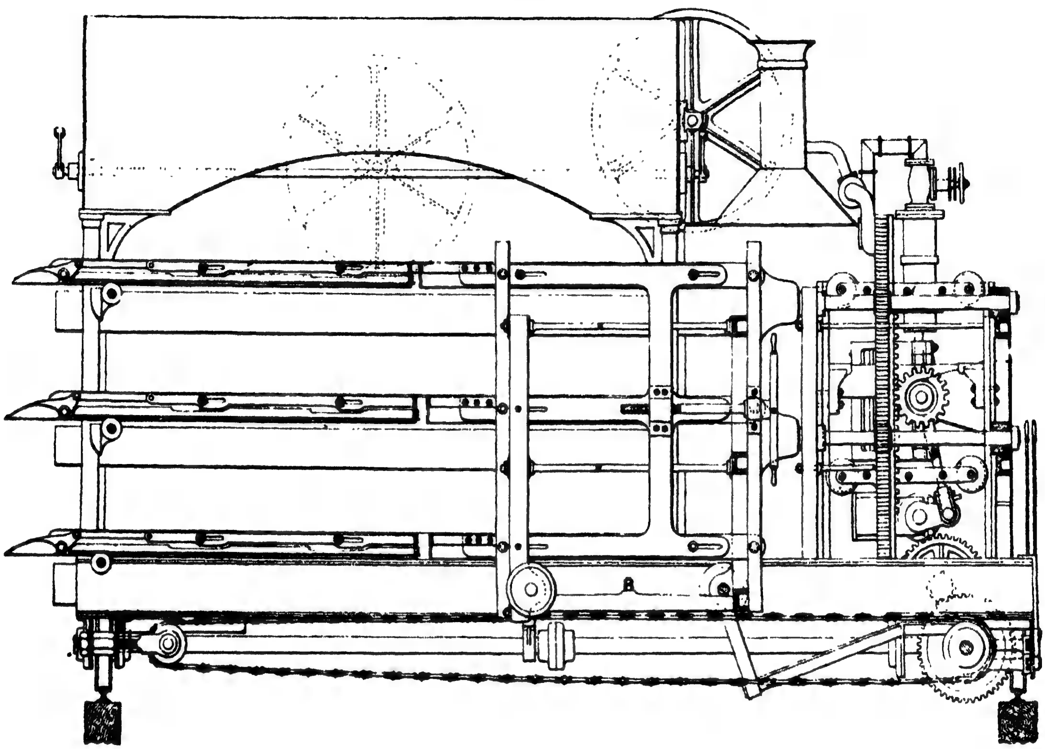


nearly the width of the retort, suspended freely upon the curved end of the rod, so that it always hangs in position. When the rake is pushed forward the slipper S is of course downwards, but on reaching the back of the retort a half-turn of the rod, R, R throws the slipper upwards, and allows the rake to fall into position for drawing, while any tendency on the part of the rake to rise and slip over the coke is checked by the immediate contact of the slipper S with the roof of the retort. The rake rests on sheaves P attached to a light framework of iron F, furnished with wheels W so as to run on the same rails as the trolly. The sheaves are attached to slides B, which are suspended from a chain passing over the pulley E to the drum X, which is fixed to the front of the framework, and turned by a worm and wheel Y.

Fig. 1374 is of Best and Holden's machine; to suit it the retorts are arranged so that the mouths of three can be opened and shut at once, the doors being at the same time constructed so as to fit tightly without luting. In front of the benches, and along the whole length of the retort house, rails are laid down upon which the carriage carrying the machinery moves. A strong framework of iron beams supports the steam engine and the rest of the apparatus, the engine being of the kind used for steam cranes, and having the different wheels and handles for giving motion and reverse motion to all the various parts. The travelling of the carriage to and fro, and the whole labour of the machine is worked by the engine, which is under the control of one man. At right angles to the line of rails in the retort house, and parallel to the length of the retorts, two small carriages travel on the framework of the machine. These carriages are side by side, one of them carrying three rakes, and the other three scoops. Above the machine is a large hopper for containing the coal, and by means of traps or valves the three scoops can be simultaneously filled with the proper quantity of coal. The machine having been brought to a stand so that the three rakes are opposite

the door of three retorts, the door is opened, and the cradle carrying the rakes is propelled forward by means of a pinion and chain. As the rakes enter the retorts the flaps at the end are horizontal; but directly they reach the extremity of the retorts the flaps are, by means of a screw, brought down into a vertical position, and at the same moment the rakes rapidly recede, and draw with them the whole contents of the retorts. The machine traverses along the rails till the cradle carrying the three scoops is opposite the retorts that have just been emptied. The scoops having

1374.



been filled with coal from the hopper are, in their turn, thrust forward, and by a self-acting movement at the proper moment inverted, and they deposit their load evenly from end to end of the retorts. They are then withdrawn, the door is closed, and the machine moves forward to repeat the operation.

Holdein's charging machines, Fig. 1375, erected at the Beckton Works, are driven by an endless wire rope from a stationary engine at the end of the retort house, and each machine consists of a framework mounted on wheels supporting carriages, to which are attached three rakes and scoops. The rakes and scoops can be swung out at right angles to the retorts, so that only one or two may be charged or drawn; thus any one of the three may be left for scurfing or repair, while the other two in the same file may be at work. This machine does not carry its own coal, but the scoops have to be filled by hand; arrangements can be made for filling them from a shoot at the back of the stage, the scoops swinging round to receive their charge of coal, and back again to deposit it in the retort. The mouth-pieces are closed singly, and have one ascension pipe to each.

Various descriptions of materials have been proposed for the formation of mains for gas, but the only description of main besides the cast iron which has met with any degree of success is formed of leaded sheet iron of a thickness corresponding with the diameter; for the smallest kinds the sheets do not exceed No. 20 B.W.G. in thickness; whilst the largest are 18 in. diameter, No. 16 gauge. When made the sheet is cut to the desired length and width, and formed cylindrical by passing through rollers; it is then riveted and soldered along the seam, when corresponding metal screws composed of lead and antimony are cast in suitable moulds at each end of the pipe, and are afterwards soldered thereto. Each pipe is then tested by hydraulic pressure in order to detect any leakage, after which it has a coating of hot pitch both inside and outside, and completed by a layer of asphalt intermixed with fine gravel of about ½-in. thick over its exterior.

When laying these pipes, a hempen washer dipped in tallow is placed on the flange which forms part of the screw; they are then screwed up by means of a short wooden lever with a cord which passes around the pipe, answering the purpose of the ordinary gun-barrel tongs. To attach a service, the asphalt is chipped off from the part, a hole is bored in the main, and into this is inserted the end of the lead pipe constituting the service, which is then soldered. This effected, the asphalt is heated and replaced on that portion of the pipe where it was chipped off.

The gas mains almost universally adopted are cast iron, and they are unquestionably preferable to all others.

The diameters of mains will depend on the quantity of gas required to be delivered by them, together with their length and position as regards level. A main ascending from the works will deliver a greater quantity than another on a level, and still more than another which descends, since for every 10 ft. of increased height above a given point, the gas in the main, in consequence of

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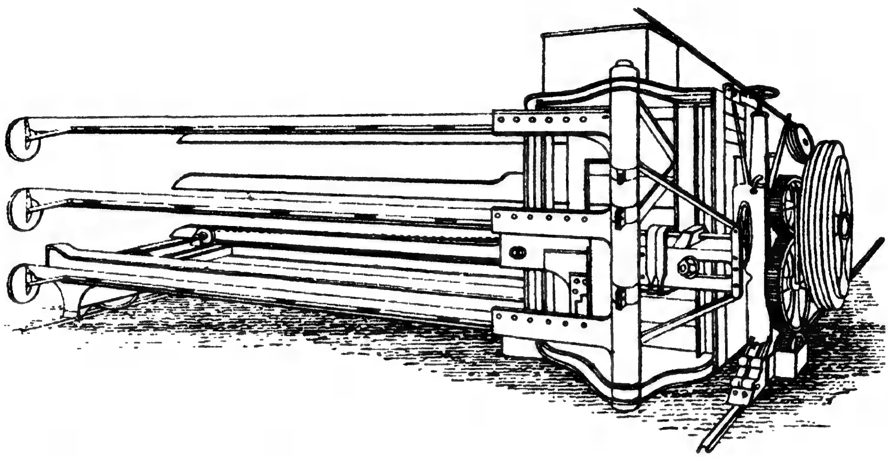


its low specific gravity, acquires an increase of about one-tenth of pressure. Thus if we suppose at the works a pressure of five-tenths to exist in a main from which there is no draught, then at a point 100 ft. above, the pressure in the same main will be fifteen-tenths, or if we imagine a pressure of fifteen-tenths at the works, then at a point 100 ft. below there will be but five-tenths pressure. Hence the delivery under the two conditions is according to the mean pressure within the mains, and in certain localities, where the works are much lower than the town supplied, the gas can be delivered in the day time with four or five-tenths exhaust, according to the difference of elevation.

Obstructions in gas mains arise principally from the accumulation of water, where the pipes have been badly laid, or by naphthaline, which is often collected by a piece of tarred yarn projecting from the joint.

Table I. is of the weights of mains as usually employed, but as the pipes of different manufacturers vary in thickness, the weights must therefore be considered as approximative.

TABLE I.—WEIGHTS AND LENGTHS OF CAST-IRON MAINS.

Diameter of Pipe in inches.	Weight of Pipe.				Weight a yard.			Length of Pipe in feet.
	tons.	cwt.	qr.	lb.	cwt.	qr.	lb.	
2	0	0	1	16	0	0	22	6
2½	0	0	2	0	0	1	0	6
3	0	0	3	18	0	1	6	9
4	0	1	1	13	0	1	23	9
5	0	1	3	8	0	2	12	9
6	0	2	1	15	0	3	5	9
8	0	3	0	24	1	0	8	9
10	0	4	2	6	1	2	2	9
12	0	7	2	8	1	3	16	12
14	0	8	1	20	2	0	12	12
15	0	11	0	0	2	3	0	12
16	0	12	1	8	3	0	9	12
18	0	15	0	0	3	3	0	12
20	0	18	0	0	4	2	0	12
22	1	0	0	0	5	0	0	12
24	1	4	1	8	5	3	9	12
30	1	10	2	0	7	2	14	12
36	2	0	0	0	10	0	0	12
48	3	0	0	0	15	0	0	12

When laying services, all the holes in the mains should be drilled previously to being tapped, by which means the work is done in a proper manner. The clumsy method of gouging the holes has frequently occasioned serious loss.

The carbonaceous crust, a deposit from the gas, that adheres firmly inside the retorts, is the cause of frequent annoyance in all gas manufactories. This is formed by decomposition of a portion of

the carburetted hydrogen in its passage along the heated sides of the retorts to the ascension pipes, and the formation is greatly assisted by the pressure generally existing inside the retorts, which cannot be obviated except by an exhauster working at a vacuum of higher gauge than the seal of the dip-pipes. The formation of carbon is beneficial so far as it conduces to fill any cracks that may have been caused in heating up; but when it accumulates to such an extent as to perceptibly reduce the heating surface, its removal is necessary.

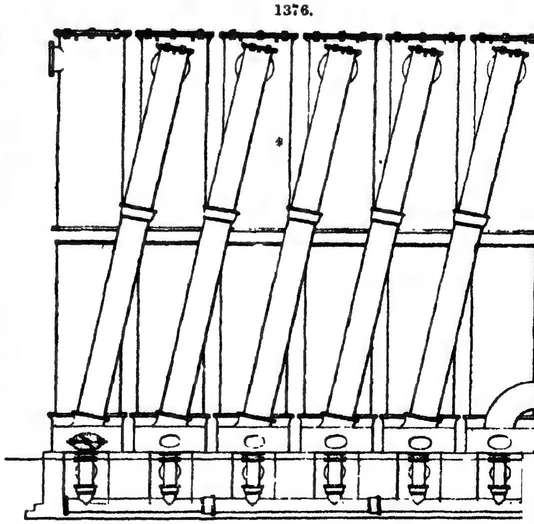
Scurfing or burning out is the process adopted, the lids being removed, and the atmosphere allowed to circulate freely in the retort, thus causing the carbon gradually to consume until, being slightly detached, a hold is gained for the scurfing-irons, by which it is ultimately, though often with great difficulty, removed. A blast or fan is sometimes employed, by means of which a current of air can be directed against any part considered most vulnerable or of greatest advantage for action with the scurfers; and the carbon is thus burnt away in a much shorter time than when left to the ordinary action of the atmosphere.

Another frequent difficulty is the choking or stoppage of the ascension pipes. The causes are generally to be found either in the pipes being too small, the irregular or improper charging of the retort, or the formation of the kiln allowing the heat to circulate too freely in the front. The main flue should be large and easily accessible. The chimney should be in such a position as to draw equally from both ends of the bench.

Pipes connected with the mouth-pieces, called the ascension pipes, conduct the gas to the hydraulic main. This is a large pipe, nearly filled with water, into which the ends of the pipes from the retorts are made to dip, and by this means form a seal by which the gas is prevented from finding its way back, either to those retorts that the workmen may be recharging, or to other parts of the bench that for the time may be out of action. Wrought iron, in preference to cast, is generally adopted in the manufacture of new hydraulic mains, its lightness, strength, and elasticity enabling it to withstand better the alternate and unequal heating and cooling of the bench; this strain affecting, by expansion and contraction, not only the main and its supports, but also the pipes in connection. The size of the main and depth of hydraulic seal are both directly dependent on, and ought invariably to be determined by, the number and area of the dip-pipes; the greatest amount of back pressure when the apparatus is in full work, should the exhauster be suddenly stopped, or require to be dispensed with; and the largest quantity of gas intended to be passed from it an hour.

When the main is hung in front of the bench it is found that, unless sufficiently far removed, the flame caused by drawing the charge acts strongly upon it, heating it to a much greater degree than when supported at the back of the ascension pipes. This heat boils the tarry fluids inside to a pitchy mass, and in cannel gas works, when a large quantity of tar comes over with the gas, causes considerable trouble. The remedy is to remove the main further from the strong heat of the bench; but where this is difficult, or unadvisable, the tar is withdrawn as completely as possible from the hydraulic main, leaving in its place the ammonia liquor, which is here plentifully deposited, and on which the heat has no other effect than to cause evaporation. A simple method is, instead of allowing tar and water to overflow with the gas, as is usually the case, to attach a pipe to the bottom of the hydraulic main, and carry it up with a bend outside to the level of the fluid that is inside the main, when the tar, being specifically heavier than the water, escapes from the bottom, overflows at the pipe, and leaves the seal inside still at the proper level. But by leaving this pipe open at the overflow, awkward consequences might ensue, and it is necessary to make a counter connection from the top of the main, which, allowing a free circulation of gas in the pipe, prevents siphoning.

1376.



The condensation of tar and ammoniacal liquor, which commences immediately after the gas leaves the retorts, renders it necessary to provide some place of deposit where the overflow of the hydraulic main and other places may be stored. The tar well is usually a brick or cast-iron tank, into which a branch pipe from the main is inserted and sealed in a stationary lute at the bottom. Still further to separate all condensable vapours before allowing the gas to pass to the purifiers, a set of condensers or coolers is provided, through which the gas is made to circulate until it is reduced to a temperature bearing some approximation to that of the surrounding atmosphere.

As has been described in this Dictionary, condensers in most cases are formed by rows of upright pipes resting on a chest at the bottom, which acts as a receiver for condensed matter. Sometimes the pipes are concentric, as in those shown in elevation, Fig. 1376, the gas passing in the annular space, and the centre is either open to the atmosphere or supplied by a constant run of cold water. Another very effective condenser is simply an oblong narrow chest, the width being no greater than the main

pipe by which it is supplied. It is usually set up on its narrow base, and the inside divided by partitions of wood in such a way as to make the gas traverse several times through the entire height before making its exit at the opposite end to that at which it had entered. The face plates are thickly studded with sockets, through which 2-in. pipes are passed and tightly pointed at both sides, and these, breaking and retarding the gas in its passage, and being kept cold by a draught of air continually passing through them, expose the gas in a comparatively limited space to an immense area of condensing surface.

Ten sq. ft. of surface for every 1000 cub. ft. manufactured in twenty-four hours, is generally recognized as sufficient for condensation; but strictly, cannel requires greater condensing area than common gas. Without attaching too much importance to this part of the apparatus, it is still essential that some approach to a definite proportion should prevail, as condensers of extravagant proportions, add unnecessarily to the cost of the works. Insufficient condensing surface is, however, the cause of continual waste, as the valuable tar oils are carried forward either to the washers or purifying vessels.

The average proportion of impurities requiring to be removed in gas made from Newcastle common coal, consists of about 1½ parts of ammonia, 8 parts of sulphuretted hydrogen, and 25 parts of carbonic acid, in 1000 of gas. A variety of other substances, generally different combinations of the same bodies, are also present; and one of these, the bisulphide of carbon, has hitherto defied all practical attempts made for its removal.

Bowditch has devised a method of removing this offensive impurity, by passing the gas through an ordinary purifier filled with heated lime and clay; but although successful on a small scale, the efficiency in large works is doubtful. Leigh states the quantity contained in 100 cub. ft. of gas to be from 13 to 109·8 grains, a considerable variation, but easily accounted for by different qualities of coal. Leigh describes a process of obtaining from gas liquor, sulphide of ammonia, which, when brought in contact with the gas, was found to combine with and remove the greater portion of the carbon sulphide. Ammonia is the first in the order of impurities which requires removal, and this is usually accomplished by employing water as an absorbent.

Ammonia as it issues from the retort combines with, and is partly neutralized by, the carbonic acid and sulphuretted hydrogen which accompanies it; and being saturated by the watery vapour of the coal, becomes condensed in what is known as ammoniacal or gas liquor; but as, after passing the condenser, a quantity of the ammonia still remains with the gas, other means for removal must be adopted.

This knowledge of the affinity possessed by water for ammonia has been taken advantage of for the purpose of removing that impurity from gas and rendering it a source of profit. The most simple means for this object is the washer, a vessel divided by a perforated plate, and half filled with water through which the gas is forced.

In the washer invented by G. Livesey, the orifices are each about the tenth of an in. in diameter, of which there is a great number; hence by these means the most minute particles of the gas are subjected to the influence of the water, the result being that 25 gals. of 10-oz. liquor are obtained from every ton of coal carbonized.

A system of washer has been invented by Cathels, wherein the gas is caused to pass through long narrow channels, situated just beneath the surface of the water; consequently fresh surfaces of each globule of the gas in its transit are brought into contact with the water, by which the ammonia is eliminated. Three of these vessels are placed at different elevations, in order that the liquid of the second can flow by gravitation to the first, and that of the third to the second washer. The foul gas enters the lowest, and passes off at the highest vessel, which contains comparatively pure water. Hence the main object of all washers of modern construction is to bring the gas in the most minute particles into communication with the water, so that the ammonia may be absorbed.

By washing in this way, however, a quantity of the oily hydrocarbons are also absorbed, and the additional pressure necessitates an increased power of exhauster.

Scrubbers effect the same purpose, they have separate divisions, are charged with coke, bricks, drain pipes, tiles, thin boards or other substances, presenting a large surface to the action of the liquid and gas, according to the judgment of the engineer; but coke is most generally employed. When in action, water is allowed to enter in a limited stream at the top of the scrubber, and is distributed over the area by some mechanical contrivance, or other means, and in descending, percolates through the coke, thus presenting a large area of wet surface.

Although the purification of gas commences at the hydraulic main, is continued with the condenser, and further advanced with the scrubber, the vessels which eliminate the sulphur compounds, carbonic acid and sulphuretted hydrogen, are particularly known as the purifiers.

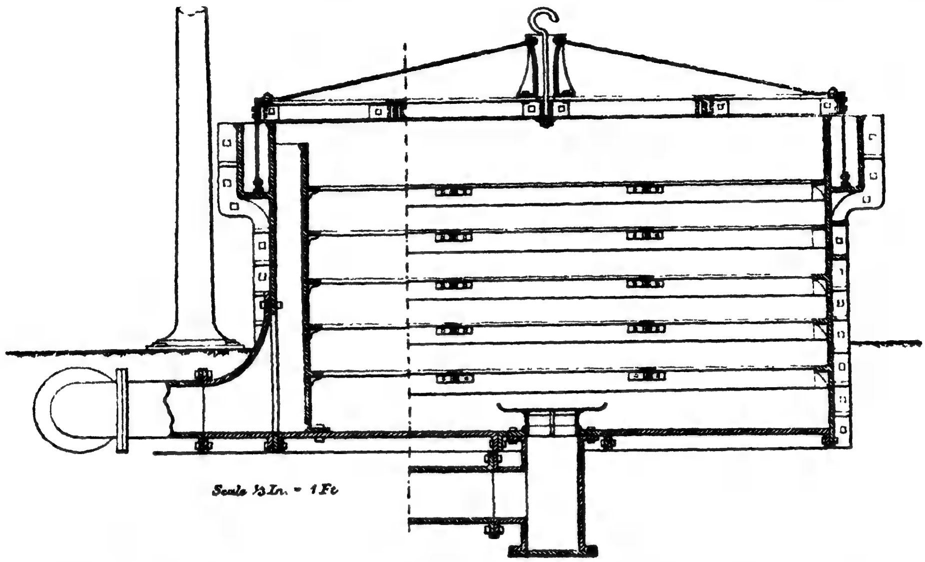
Fig. 1377 represents one out of a set of purifiers in connection with a central valve that allows the gas to pass into and out of each in succession. The bottom is formed of twelve iron plates with flanges of about 2½ in. wide and secured by bolts and nuts 6 in. apart, strengthened by brackets placed between them, the bolt holes being cast in the flanges midway between the brackets. Around the edge is a corresponding flange, to which the vertical plates forming the sides are bolted, which plates are put together with lap plates, the whole of the joints being made with iron cement.

When in action, the gas to be purified enters into the centre of the valve; from there the gas is conveyed into the first purifier of the set; when, after passing through the lime or oxide, it returns to the valve and passes to the second, and so on, eventually flowing to the store or gas-holder. When in the course of time the material in the first purifier becomes ineffective, this is thrown out of action, and another brought into use. Test taps are usually placed on the covers of the purifiers, and are generally ⅛th-in. cast iron, as brass corrodes very rapidly; but when the purifiers are not divided in the centre, test taps may be placed midway in the side of the purifier, so as to ascertain the purity of the gas before passing through the last apparatus.

In order to determine the magnitude of purifiers, the first consideration is the maximum daily production of the works for which they are intended, and as gasworks invariably increase in-

importance, it is always advisable to make the apparatus of ample magnitude. The maximum daily make being ascertained, the general rule in small and medium works is to allow a purifying area of 1 sq. yard for each 1000 ft. of gas, 10 sq. yards of grid a ton of coal carbonized in the twenty-four hours. This with four purifiers, three of which are always in action, gives $7\frac{1}{2}$ sq. ft. of active surface production.

1377.



No gasworks, even of the most limited capacity, can be properly conducted with less than two purifiers, each of which in very small works should be subdivided and connected, in such a manner that the gas in passing ascends through the purifying material in the first compartment, and descends through that in the other; one purifier being in action whilst the other is being charged ready for use.

By the combined action of the hydraulic main, the condenser, and scrubber or washer, the whole of the tar and ammoniacal liquor, together with a portion of the carbonic acid and sulphur compounds, are, or at least should be, eliminated from the gas; but there still remains the larger portion of the two last-mentioned impurities to be removed before it is in the condition to be delivered to the consumer. Gas can be considered commercially pure, and in the ordinary sense of the term, free from all noxious elements, when, after a lengthened exposure to the usual tests for carbonic acid, ammonia, and sulphuretted hydrogen, no indication of these impurities exists.

As already stated, the most perfect system of purifying gas is by means of wet lime, or, more properly speaking, by the solution called the "cream of lime," and although the odour arising from the foul material, after being employed, is sufficiently offensive to prevent the adoption of this mode of purification under ordinary circumstances, there are, however, localities where the isolated position of the works permits of its application.

For this purpose three purifiers are generally employed, somewhat similar in construction and action to Fig. 1377, but so situated that, when desired, the liquid in the highest can flow to the second, and from there to the third.

Vessels are provided with agitators, actuated by the bevel wheels on the top of the axles, driven from a steam engine. Thus, by the mechanical action of the agitators or stirrers, the lime is always maintained in a state of solution, and as the gas is caused to pass through very contracted spaces, it is broken up into small particles, and these, coming in contact with the lime, the impurities are absorbed.

Although the purification by wet lime is efficacious and economical, there exists the difficulty of disposing of the foul material, technically called "blue billy." Of this a portion may be employed as luting for the mouth-pieces of retorts where that is used, but there still remains a large quantity which yields a most offensive odour, and in consequence is extremely difficult to dispose of, but wherever this can be effected, and the works are distant from any population, the wet lime process may be adopted with advantage.

In the next method of purification by means of dry lime, the moistened hydrate of lime is placed on the sieves or grids of the purifiers to a thickness of 3 or 4 in., the whole being well and completely covered and of uniform thickness. Some purifiers are subdivided, thus the gas has to ascend and descend through the lime, passing as it were through six distinct purifiers, although but three are employed.

It is generally accepted as a rule that a bushel of quicklime, which, when slaked and rendered into hydrate, increases to about $2\frac{1}{2}$ times its original volume, is sufficient by the process in question to purify the gas derived from a ton of coal. This, however, must greatly depend on the quality of the lime, for there are some descriptions which contain a large percentage of clay; and although

admirably adapted for the manufacture of hydraulic cement, they are ill suited for the purification of gas.

Another consideration is, that some coals contain considerably more sulphur compounds than others, therefore no general rule can be defined; but when properly treated, and the lime of average quality, the quantities stated alike for wet as dry lime, may be accepted as a good approximation to that required for the purification of gas.

In the ordinary method of purifying, the foul gas is admitted first into the purifier the most impregnated with impurity, thence it passes to the second, and so to the third, where the lime is comparatively clean. When purifiers are of ample magnitude, the foul lime if properly moistened remains an active agent in the purification to the last, therefore it is only when the gas begins to indicate signs of impurity at the fifth division, supposing six divisions of purifiers to exist, that they should be changed, and by the employment of apparatus of ample capacity only can the lime be employed to the best advantage.

The superiority of the dry-lime process consists in the facts that by it the pressure in the retorts is materially decreased, which is a great consideration in small works where the exhauster is not employed, and the foul residuum creates no particular nuisance when moderately distant from habitations, and is readily disposed of for agricultural purposes; whilst by this process, as with the other, all the various impurities of the gas can be eliminated.

The cheapest and least expensive material for the purpose is however oxide of iron, which is used slightly moistened and charged in much thicker layers than lime, but to what degree must depend on its nature and weight, together with the size of the purifiers. The thicker the layer the better, so long as the pressure is not inconveniently increased. When taken from the purifiers, the spent oxide has a dull black purple appearance, and is then laid a thickness of 8 or 10 in. on the ground for the purpose of revivification, being occasionally turned over and broken up from day to day, in order to expose all its particles to the action of the atmosphere, and when it resumes its original colour it is suitable to be again employed. Fresh oxide has a tendency to ignite when first used, for this reason only a portion of new material should be intermixed with the old as occasion may require.

Different engineers employ different methods of purification, but in the majority of works lime is used for the purpose, either as the cream of lime or the hydrate of lime, properly moistened, by either of which processes the whole of the impurities can be removed so that the gas is rendered commercially pure. In other works the use of lime is unknown, the purification being effected by the condenser, scrubber, and oxide of iron; and in a few cases the carbonic acid is eliminated, so far as practicable, by means of the ammoniacal liquor in the scrubber or washer, and sometimes a percentage of cannel is employed, to compensate for the deterioration of the gas by the presence of a small quantity of carbonic acid. Again, in other establishments, the sulphate of iron and lime are exclusively employed.

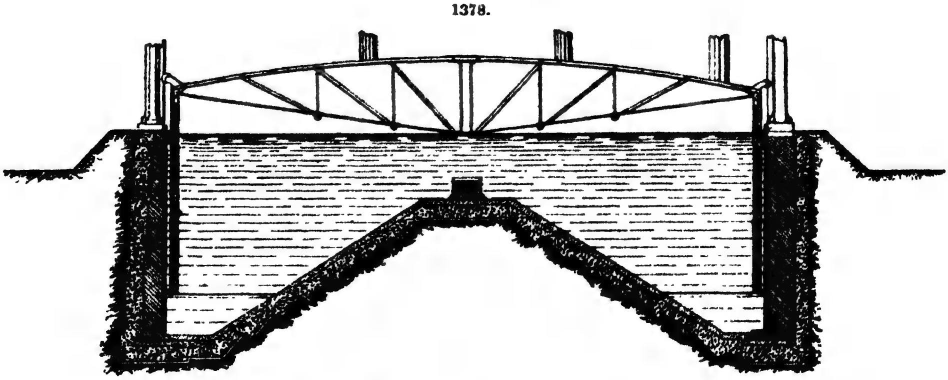
Then, as regards the ammonia; instead of eliminating this in the washer or scrubber, the gas is caused to pass through an ordinary purifier, charged with breeze or sawdust, saturated with dilute sulphuric acid, but used in a dry state, a process to be recommended in small works, by which the residuum may be preserved and rendered a marketable commodity, but in works of 20,000,000 ft. a year and upwards the scrubber or washer, or both combined, should eliminate the ammonia.

Again, the method of purifying in some establishments is reversed. Instead of the foul gas first entering the foulest purifier, it is caused to pass into vessels called carbonaters, containing clean hydrate of lime, by which the carbonic acid is absorbed, and from thence the gas passes into other purifiers, containing the sulphide of calcium, and subsequently to the oxide of iron purifiers, to eliminate the remaining sulphuretted hydrogen. This process, although effective, is very costly.

Fig. 1378 is a section of a tank and gas-holder, the latter having a single lift and being 70 ft. diameter.

The larger the dimensions of a proposed gas-holder, the more cheaply it can be constructed for

1378.

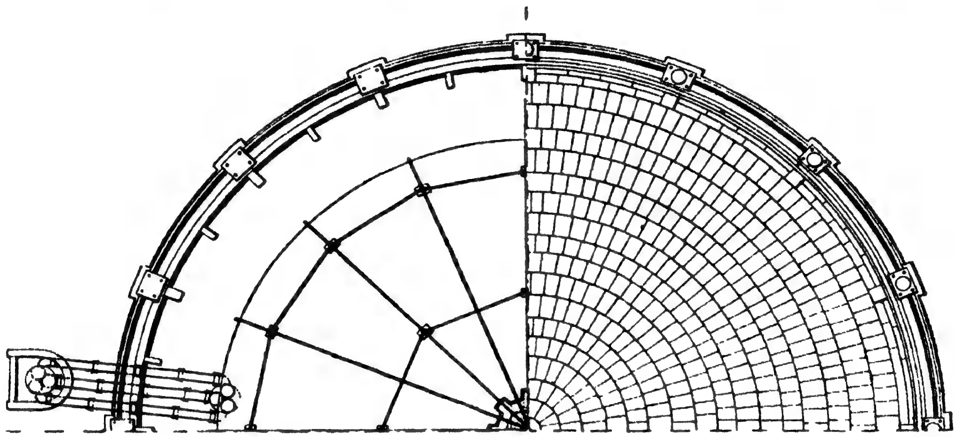


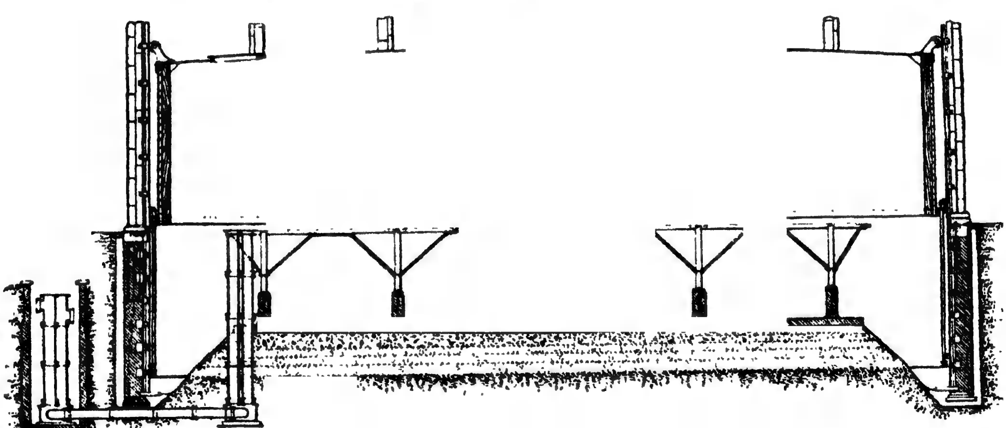
each 1000 cubic feet of contents. The rule generally adopted is to construct gas-holders as large as from the nature and extent of supply is deemed advisable. The Commercial Gas Company have one 206 ft. in diameter. At the Horseferry Road station of the Chartered Gas Company, the tank of one gas-holder is 202 ft. diameter by 25 ft. deep. The excavation of this tank is a trench 12 ft.

deep by 5 ft. in width all round; the sides are formed by $\frac{5}{8}$ in. B B Staffordshire plates, riveted so as to be watertight, with $\frac{3}{4}$-in. rivets; the bottom is secured on the top by 3-16ths sheet iron, underneath which is a layer of bricks and a thick bed of concrete.

At the Kennington Lane station of the Phœnix Gas Co., London, there is a gas-holder 160 ft. diameter by 70 ft. high, which is peculiar in its construction. Fig. 1379 is a plan of this holder partly in section, Fig. 1380 a sectional elevation. Contrary to custom, the columns are made of $\frac{3}{8}$-in. and $\frac{1}{2}$-in. boiler plates, the diameter of each being 3 ft. 3 in. at the base, tapering to 2 ft. 8 in. at the top; the total height of the columns is 73 ft., and each column was erected in one piece.

1379.





1380.

Cast-iron girders round the top of the columns are dispensed with, 2 in. and $1\frac{1}{2}$ in. round rods being used instead; and the gas-holder crown, when working, is entirely unsupported by framework. To prevent collapse, should the holder come to the ground, a wooden frame upon brick piers was constructed inside the tank, and this has proved a perfectly sufficient safeguard.

In small works, single lift gas-holders are generally hung with counterbalance weights, and these, when capable of being conveniently shifted, serve to regulate the pressure, and save the construction of a governor; but in larger works, where a governor is employed, the dimensions of the gas-holder are calculated so that a uniform pressure may be given without the aid of a counterpoise. This is accomplished on the principle that, the weight of the holder being known, a quantity of water equal in weight will be sustained by it, and the depth of this column, depending on the superficial area of the holder, may be calculated when the diameter is ascertained.

It is therefore evident, that the smaller the diameter compared with the total weight, the greater will be the pressure exerted. Gas-holders of a very large diameter compared with their depth, frequently require weighting rings of iron attached to some part of the framing, in order to give a column of water equal to the specified height. It is customary to make gas-holders of very large dimensions on the telescopic principle, that is, composed of two or more lifts. The inner carry their own water-lutes. By this means ground space is greatly economized, and the saving in tank excavation and building reduces the cost. The lutes are liable to become frozen in extremely cold weather, but this may be guarded against by the introduction of a steam pipe, which will always prove a sufficient remedy when necessity arises for its use.

The pressure of a holder is determined by its weight as compared with its area: thus, when of

large diameter and shallow depth, with average strength of sheets and trussing, the pressure is limited accordingly; but when the holder is of small diameter and great depth, the pressure is always excessive. The height of the holder should be about one-third its diameter. With telescopic holders, the height of the two lifts is usually equal to two-fifths the diameter of the holder, and in most cases, alike in single as well as telescopic holders, the rise of the dome is equal to $\frac{1}{10}$th of the diameter.

Gas-holders of small dimensions are generally constructed with their sides of No. 16 gauge sheets, and the top or crown of No. 14 or 15 gauge; holders of 60 or 70 ft. in diameter are often made of the thickness indicated, except in the sheets riveted to the bottom and top angle-iron, which are augmented in strength by one or two numbers of the gauge. The durability of these vessels under average conditions, constructed of No. 16 gauge, may be twenty-five years; whereas by the addition of $\frac{1}{4}$th more to the thickness of the metal, their duration can be fairly estimated at double that period. To ascertain the weight of a single gas-holder, when not counterbalanced, of a given area and pressure;—

Table II.—Pressure with Various Columns of Water.

		in.			lb. a square ft.
Column of water		1	equal to pressure of		5·208
"	"	2	"	"	10·416
"	"	3	"	"	15·624
"	"	4	"	"	20·833
"	"	5	"	"	26·040
"	"	6	"	"	31·248
"	"	9	"	"	46·872
"	"	12	"	"	62·500

Suppose the weight of a holder to be required, the diameter of which is 50 ft. and the pressure given by it to be 4 in. Then the area of this will be 1963·5 feet; and on referring to Table II., we find the weight of each sq. ft. corresponding with the pressure mentioned to be 20·833 lb., when the area multiplied by the weight a ft. gives 40,904 lb. as the weight of the holder.

Having the weight of the holder and its diameter or area, to find the pressure, the weight 40,904 lb. divided by the area 1963·5 gives 20·8332 lb., which on reference to Table II. corresponds with 4 in. as the pressure required.

The weight and pressure being known, the area of the holder may be ascertained by dividing its weight by the column of the pressure. Thus 40,904 lb. divided by 20·8332 lb., the weight of a column of water 4 in. high, gives 1963·5 ft. as the area of the top of the holder.

When ascertaining the weight of gas-holders by this method, the ascending power of the gas must be taken into consideration, and this may be averaged at 40 lb. for each 1000 ft. of gas in the vessel; hence, if this be 15 ft. in diameter and 16 ft. deep, containing 30,000 ft., it would act with an ascending power of 1200 lb., which would have to be added to the weight.

The pressure of a holder varies slightly according to its position, or the degree to which the sides are immersed in the tank, in consequence of the increase of the weight of the iron when out of the water; this, with single holders of ordinary construction, is insignificant, and practically need not be taken into consideration.

When erecting a gas-holder, scaffolding is first fitted up in the interior of the tank, leaving room for the sides of the holder to descend, in such a manner that planks may be placed at the desired point to enable the men to rivet the plates of the roof. Planks are then placed around the top of the tank, and on these the parts forming the bottom curb of the holder are adjusted, and riveted or bolted together. This effected, the bottom row or two rows of plates are placed in their positions and the circle riveted, when the bottom frames with their rollers are securely bolted, exactly opposite to their respective guides. A number of long screws corresponding with the columns are provided, each about 7 ft. long and 1½ in. diameter, having a hook at one end. A nut works freely on the screw, and beneath this nut is a swivel, so arranged that it can be attached to the guide standards.

The swivels of the long screws being bolted to their respective standards, then by turning the nuts the screws are raised to nearly their highest point, when each of them by means of a chain and hook grapples the bottom curb; then on raising the screws still higher, that portion of the holder is suspended. The planks are then removed, and by the action of the nuts, the whole is gradually lowered to the desired depth ready to place another row of plates. Thus all the side plates are riveted and lowered as required, when the top curb is also riveted.

The crown plate with the centre pipe are then placed in their position, and the main and secondary bars are bolted to the curb and crown plate. The tension rods, struts, and suspension rods are then fixed, and the bracket bars riveted or bolted, thus forming the trussing of the roof. The plates covering the roof are then temporarily placed over the whole area, and when accurately arranged they are then riveted, when the holder is lowered to its bearings and the long screws removed. This effected, the upper guide rollers are then fixed accurately in their positions. A manhole is left in the roof, so that after the interior of the holder is painted, the scaffolding can be removed at that point; it is also intended for the purpose of clearing out any obstruction that may occur in the pipe.

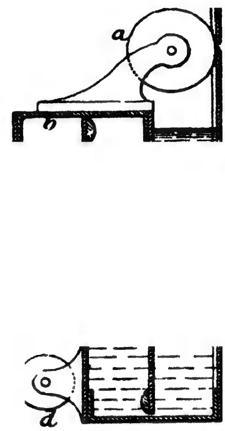
The telescopic holder, which under some conditions is advisable, is comprised of a single vessel of the ordinary construction, guided at the top by rollers working against the guide standards, and surrounded at its base by an annular cup *c*, of from 12 in. to 18 in. in depth and from 6 to 9 in. in width, Fig. 1381. This inner holder is enclosed by a cylinder or outer lift concentric to it, of somewhat larger diameter, but about the same depth. To the top of this outer cylinder is attached an annular grip *b b*, corresponding with the cup. Thus, each time that the inner holder is filled when

ascending, it lifts the lower holder, and as the cup is always filled with water when rising, on the grip being immersed therein a hydraulic joint extending the circumference of the holder is formed. By these means, so long as the holder retains its level position, and in the absence of a pressure superior to that of the dip, the gas is retained. The rollers *d* and *a* are for the purpose of preventing any unnecessary play, which would be fatal to the action of the apparatus.

In telescopic holders of 90 ft. in diameter and under, the upper lift is generally counterbalanced, but when of larger dimensions their great area renders this no longer necessary.

The choice of a position for a large gas-holder, where choice can be had, requires careful and judicious inquiry on the part of the engineer. Rocks and water-springs ought, if possible, to be avoided; the first largely increasing the cost of excavations, and the latter endangering the stability of the walls of the tank, besides seriously impeding their construction. A stiff loamy soil is preferable to a sandy or porous one, assisting as it must do the clay-puddling, which is generally found necessary to keep the tank water-tight. Should a workable sand be found, it may be used in the water and concrete.

1381.



When a pressure of gas or atmospheric air is first introduced in an empty holder, an instantaneous effect is observable on the crown and side plates. The crown plates are quickly forced out, and the gas-holder generally begins to have a smooth, rigid appearance, very different from the uneven surface it presented when simply supported by the framework.

The true support of a gas-holder crown when working is therefore the pressure of gas inside, and although certainly advisable to construct a light supporting framework, this only becomes useful when the gas-holder is at rest, and should in no case be complicated or expensive. There is no doubt that with sheets of sufficient thickness in the outer circle of the crown and top rows of the circumference, a very light framing indeed ought to be sufficient.

Proper storage capacity saves retorts and stokers' wages, reduces the percentage of fuel, and prevents the danger of a short supply in the depth of winter.

In estimating the lighting power of gas, photometers are employed.

The jet photometer consists of a steatite jet fixed upon a very delicate King's pressure gauge, capable of indicating to at least $\frac{1}{100}$ of an inch water pressure. The gas is made to pass through the gauge to the jet, and the pressure is regulated by a delicately adjusted dry or wet governor. The instrument is sometimes enclosed in a wood casing with a glazed door. A scale of inches and parts is engraved on the glass, and a corresponding scale in porcelain is fixed at the back of the cupboard inside. The base-line of each scale coincides in level with the top of the jet. This plan of enclosure originated with Sugg. Sometimes the jet is surrounded by a glass chimney graduated in inches and parts. With these instruments twelve-candle gas issuing at $\frac{6}{10}$ pressure should be 6 in. long. Bannister suggested, in 1863, the possibility of making an instrument to register continuously, during a number of hours, the height of the flame; and Kirkham and Sugg have apparatus in which the height of the jet-flame, and the acting pressure, are registered by photographic means.

One of the most convenient specific gravity apparatus for testing gas is Schilling's, which consists of a cylindrical glass vessel and an inner movable glass tube, the latter fitted at its base with a metal foot or stand, and at the top with a metal cap, which is provided with a cock to admit gas, and with a central cock having two ways, one for the admission of air to the glass tube, and one for the discharge of air and of gas in the experiment. By this apparatus the specific gravity is determined by the times required for the discharge of equal volumes of air and of gas, through a minute orifice in a platinum plate mounted on the nozzle of the central cock. The square of the number of seconds required for the discharge of the gas divided by the square of the number of seconds required for the discharge of air, gives the specific gravity of the gas. No correction is needful if the temperature of the air and gas be equal, and to secure this there is no difficulty. If the time of discharge for air be 240 seconds, and for gas 180 seconds, the squares would be 57,600 and 32,400; dividing the latter by the former 0·562 would be the quotient, and the specific gravity of the gas. This subject is too large to be further treated here.

Books relating to Gas.—Richards, W., 'Practical Treatise on the Manufacture and Distribution of Coal Gas,' 4to, 1877. Hartley, F. W., 'The Gas Analyst's Manual,' crown 8vo, 1879. Bower, G., 'The Gas and Water Engineer's Book of Reference,' 4to, 1880. King 'On the Manufacture of Coal Gas,' 2 vols., 4to, 1877–80.

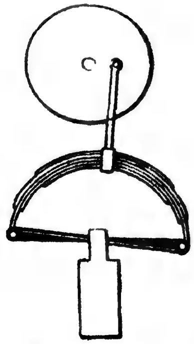
HAMMERS.

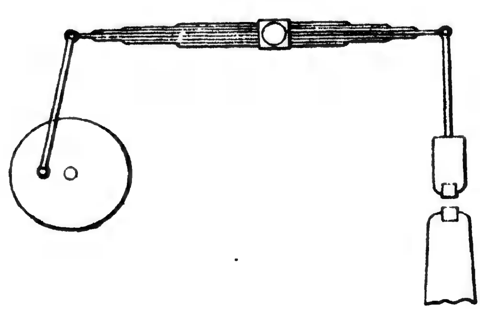
The term power hammer is generally applied to those hammers in which the power is applied by means of a belt or gearing; and is used to distinguish them from the ordinary steam hammer, in which the hammer block is attached to the piston rod of the engine; and it thus includes all varieties of friction, crank, and trip hammers.

The oldest form of power hammer is that known as the helve, trip, or tilt hammer, the construction of which was evidently suggested by the common hand hammer. It consists of a stout helve of timber bound with iron bands, to preserve it from splitting under the violent concussions to which it is subjected. This helve is supported by trunnions, working in plummer blocks, which are bolted to a strong foundation of timber, the said trunnions forming the fulcrum upon which the lever turns. To one end of this lever is attached the hammer head, and at the opposite or back end revolves a wheel provided with a series of cams, by the action of which the lever is depressed and the hammer head raised. The best method for determining the proper curve for the faces of

these cams, will be found given in the article on Gearing in the first volume of this Dictionary. The chief disadvantages attending the use of trip hammers are, the difficulty of connecting them with the driving power, especially where a number of hammers have to be driven from one shaft. The head and die of a trip hammer, weighing, together with the irons for attaching them 100 lb., and perhaps more, will make, with a helve 8 ft. long, from two to three hundred blows a minute. This motion far exceeds anything that could be attained by a direct reciprocating motion given to the hammer head by a crank, and is also greatly in excess of any rate of speed that would be assumed from theoretical inferences. The hammer helve being of wood possesses a certain amount of elasticity, and acts like a vibrating spring, its vibrations being in unison with the speed of the tripping points; and it is upon this principle of elasticity that the whole machine must be constructed, in which respect it stands as an exception to almost every other known machine; even the framing for supporting the trunnions, which without experience one would suppose required to be made as rigid as possible, is found in practice to answer best when composed of timber, this timber being disposed in such a manner as to allow it to spring and yield. The sudden and varied resistances that are offered to line shafts which drive trip hammers, tend to loosen couplings, destroy gearing, and produce strains that are unknown in other cases; shafting arranged with the usual proportions for transmitting power, soon failing if applied to drive trip hammers, and consequently all rigid connections, or metal attachments, are inadmissible, belts arranged so as to have their tension varied at will being the usual means employed for transmitting power to trip hammers, and the only one that has been successful. Further, there being no means of varying the height to which the hammer head is raised, and this head acting only through the force of gravity, the power of the blows delivered by any given hammer, must always remain constant upon a given thickness of metal; the only variation in power being in the wrong direction, that is the thicker the mass of metal being operated upon, the less powerful will be the blow delivered by the hammer, while the opposite conditions are almost always required. Again, from the fact of the hammer head moving in an arc of a circle, of which the trunnions form the centre, it follows that only when operating upon pieces of a certain thickness will the hammer deliver a flat blow, and this want of parallelism will increase, in proportion to the thickness of the mass being operated upon, those parts of the metal which are nearer to the fulcrum being unduly compressed, while the more distant portion will receive scarcely any blow. Another difficulty attending the use of trip hammers, is the rapidity with which crystallization takes place, in the attachments for holding the die blocks to the helves, where no elastic medium can be interposed to break the concussion of the dies; bolts to pass through the helve, even when made from the most fibrous Swedish iron, not lasting on an average for more than ten days, and often breaking in a single day; the safest mode of attaching the die block, and the one most generally employed, is to forge it solid, with a band to surround the end of the helve.

Another class of power hammers consists of those which are operated by means of a crank, the connection between which and the hammer head consists either of some kind of deflecting spring, or of an air cylinder, and to this class therefore belong all the various forms of pneumatic hammers. The great advantage possessed by these hammers over the older helve, consists in the fact that the blow delivered by the tup always remains parallel to the face of the work, no matter how much the latter may vary in thickness; while at the same time, they generally possess some arrangement by means of which the power of the blow may be varied, to suit the constantly changing requirements of the work operated upon. In Fig. 1382 is shown a diagram of an arrangement of crank hammer having a curved leaf spring interposed between the crank and hammer, the latter being connected

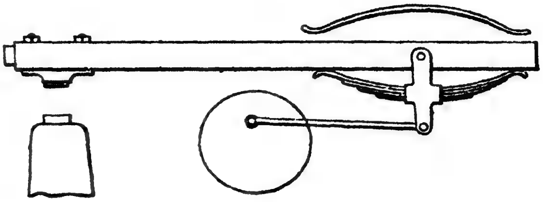




to the spring by means of a leather strap, the link being rigidly fixed to the spring. The appearance of the device in motion will not recommend it, but the effect produced, so long as the various parts last, is all that can be desired. A diagram of a later introduced arrangement is shown in Fig. 1383, which judged by the test of endurance and non-liability to derangement appears to be the best, of all those hammers constructed on this principle, which have up to the present time been introduced. The pivot is fixed on the frame, and the vibration produced by the crank is multiplied at the other end of the spring lever, so that strong, rapid blows are given by the hammer. In Fig. 1384 is shown a kind of composite machine, half trip hammer, half crank hammer. The helve and radial die movement are retained, but the hammer is operated by a crank, through what is in substance an elastic connection. Such hammers as these here described are well adapted for light work and small pieces, as on account of the light weight of the reciprocating

parts they can be driven at very high speeds; but, as is the case with all hammers having a fixed range of movement and fixed anvils, the intensity of the blows diminishes as the thickness of the work increases, which, as already pointed out, is the reverse of what is required. This objection is increased or diminished according as the length or range of stroke is long or short; and when the parallelism of the dies changes also with the thickness of a piece, as in the system of construction shown in Fig. 1384. We must therefore conclude that, for general purposes, considerable effect must be sacrificed in attaining rapid blows in the manner here explained; while a dead blow, or stop motion, which is almost indispensable in most kinds of work, would not be at all easy to apply in the case of a hammer operated by springs.

1384.



The two earliest inventions for steam hammers were those of James Watt, in 1784, and of William Deverell in 1806; but it was not until about the year 1843 that the first steam hammer was made at the Bridgewater Foundry by James Nasmyth, who had taken out a patent for the same in 1842; and though this was far from being the perfect machine which we are now accustomed to see, its erection marked the commencement of a new era in the history of the iron trade, for without the possession of this valuable invention it would have been simply impossible to execute the gigantic forgings of the present day. A steam hammer is in its main features an extremely simple machine, one of the principal problems in connection with its manufacture being how best to resist the destructive effects resulting from the concussion of its blows. It therefore follows from this that weighty economical reasons exist for separating into detail, as much as possible, whatever is liable to break; but there is also another reason for this, which applies especially to power-driven hammers. Joints, however firmly they may be bolted together, still impart some elasticity, and however suitable cast iron may be for the framing of most kinds of machines, it is, as is well known, wanting in that elasticity which hammer frames seem to require. It is not assumed that joints when rigidly bolted together can impart much elasticity, but if the frame of a hammer be cast in one piece, or even as was formerly sometimes done, the cylinder cast solid with the framing, it is at once obvious that the liability to fracture will be considerably increased. In watching the course of practice in steam hammer construction, there are certain plans which, for details such as valve gearing, are gradually becoming general; of these the pendulous swing bar operating by sliding on the hammer head is one of the principal. The reason for this is obvious enough at the present time, when it is known how difficult it is to maintain any positive connection with a hammer head; a link, lever, or tappets, or any device to which the shock of the blows is imparted soon giving way; but a swing bar, bearing lightly against the hammer block, and nearly in the plane of motion, is but little affected by the concussion.

John Richards, in his treatise on the 'Principles of Shop Manipulation,' when treating of steam hammers, gives the following particulars of the principles of their construction and operation.

"The direct application of steam to forging hammers is beyond question the greatest improvement that has ever been made in forging machinery; not only has it simplified the operations that were carried on before its invention, but it has added many branches, and extended the art of forging, to purposes that could never have been attained except by the steam hammer.

"In forming a conception of steam hammers we must not fall into the common error of regarding them as distinct machines, or as operating on new principles. A steam hammer is nothing more than the common hammer driven by a new medium, a hammer that receives power through the medium of steam, instead of by belts, shafts, and cranks. The steam hammer supplies other purposes besides transmitting power, and seems to be so perfectly adapted to fill the different conditions of power hammering that there seems nothing left to be desired; for it will be seen that steam as a driving medium for hammers fulfils the following conditions;—

1. "The power is connected to the hammer by means of the least possible mechanism, consisting only of a cylinder, a piston, a slide valve, induction pipe, and throttle valve; these few details taking the place of a steam engine, shafts, belts, tension pulleys, cranks and springs, with pulleys, gearing, and all details that are required between the hammer head and the steam boiler in other cases.

2. "The steam establishes the greatest possible elasticity in the connection between the hammer and the power, and at the same time cushions the blow at both the top and bottom of the stroke, or on the top only, as the case may require.

3. "Each blow given is an independent operation, and can be repeated at will, while in other hammers such changes can only be made throughout a series of blows by gradually increasing or diminishing their force.

4. "There is no direct connection between the moving parts of the hammer and the framing, except the lateral guides for the hammer head; the steam being interposed as a cushion in the line of action, reduces the required strength and height of the framing to a minimum, and avoids positive strain and concussion.

5. "The range and power of the blows, as well as their time, are controlled at will; this is the greatest distinction between steam and other hammers, and the particular advantage that has led to their extended use.

6. "The power is transmitted to the hammers through a small pipe, that may be carried in any direction and for almost any distance at a very small expense, so that the hammers may be placed in such positions as will best accommodate the work, without reference to shafts or other machinery.

7. " There is no waste of power by slipping belts or other frictional contrivances to graduate motion; and finally there is no machinery to be kept in motion when the hammer is not at work.

" One thing more remains to be noticed, namely the valve motions, which are a matter of some intricacy, but without which all that has been explained would fail to give a proper idea of steam hammer action.

" Steam hammers are divided into two classes, one class having the valves moved by hand, and the other, automatic valve movement. The action of the automatic hammers are again divided into what is termed the elastic blow, and the dead blow. In working with elastic blows the steam piston is cushioned at both the up and down stroke, and the action of the hammer corresponds to that of a helve trip hammer, the steam filling the office of a vibrating spring; the hammer gives a quick rebounding blow, the momentum being only in part spent upon the work, and partly arrested by the cushioning of steam in the bottom of the cylinder under the piston. Aside from the greater rapidity with which a hammer may operate when working on this principle, there is nothing gained and much lost; and as this kind of action is imperative in any hammer that has a maintained connection between its reciprocating parts and the valve, it is perhaps fair to infer that the reason why most automatic hammers act with an elastic blow is either from a want of knowledge as to a proper valve arrangement, or because of mechanical difficulties in arranging valve gear.

" In working with dead blows no steam is admitted under the piston until the hammer has finished its down stroke, and expended its momentum upon the work. So different is the effect of these two plans of operating, that on most kinds of work a 50-lb. hammer working with dead blows will perform the same duty that one of 100 lb. will when acting with elastic or cushioned blows. This difference between the dead and elastic stroke is so important that it has served to keep the [illegible] in use in many cases, where much could be gained by automatic hammers that [illegible]

" The valve gear of [illegible] elastic blow, furnishes one of the most interesting examples of m[illegible] stated that to give a dead or stamp stroke, the valve must move and admit steam beneath the piston after the hammer has made the blow, and stopped on the work, and that such a movement of the valve could not be imparted by any maintained connection between the hammer head and valve. This problem is met by connecting the drop or hammer head with mechanism that will by reason of its momentum continue to move after the hammer head stops. This mechanism may consist of various devices. Massey in England, and Ferris and Miles in America, employ a swinging wiper bar that is, by reason of its weight or inertia, retarded and does not follow the head closely on the down stroke, but swings into contact and opens the valve after the hammer has come to a full stop. By holding this wiper bar continuously in contact with the hammer-drop, elastic or rebounding blows are given, and by adding weight in certain positions to the wiper bar, its motion is so retarded that the hammer will act as a stamp or drop. A German [illegible] employs the concussion of the blow to disengage the valve gear and effect this after movement [illegible]

[illegible] hammer action in forging processes [illegible] no little importance in the heavier class of work. When a piece is placed on an anvil and struck on the top side with a force of one ton, the bottom or anvil side of the piece does not receive an equal force; a share of the blow is absorbed by the inertia of the piece, and the effect on the bottom side is, theoretically, directly as the force of the blow, less the inertia of the piece acted upon. In practice this difference of effect on the top and the bottom, or between the anvil and the hammer sides of the iron, is much greater than would be supposed. The yielding of the soft metal on the top cushions the blow, and protects the under side from the force; this, because the effect produced in striking a piece of heated iron is by no means to be measured by the force of the blow. It requires, to use a technical term, a certain amount of force to "start" the iron, and anything less than this force has but little effect in starting the particles and changing the form of the piece. From this it can be seen that there must occur a great loss of power, for whatever force is absorbed by the weight of the piece produces no effect. By watching a smith using a hand hammer it will be seen that whenever the piece operated upon is heavier than the hammer, but little, if any, effect is produced on the anvil or bottom surface. Nor is this loss of effect the only one. The cost of heating, which generally exceeds the cost of shaping, is directly as the amount of shaping that may be done at each heat; and consequently if the two sides of a piece, instead of one, can be equally acted upon in shaping, one half the heating will be saved. Another consideration to be gained by equal action on both sides of large pieces is the quality of the forgings produced, which is generally improved by the rapidity of the shaping processes, and injured by too frequent heating. This loss of effect by the inertia of the piece acted upon being as the relative weight of the hammer and the piece, it follows that the loss increases with the weight of the work; not only the loss of power, but the cost of heating, which also increases with the size of the work. There is such a difference in the mechanical conditions between light and heavy forging that for any but heavy work there would be more lost than gained in attempting to evade or remedy this loss of effect on the anvil face of the work.

" To remedy this defect in heavy forging, John Ramsbottom designed what may be termed compound hammers, consisting of two independent heads or rams moving in opposite directions, and acting simultaneously upon the work which is held between them. These hammers were a

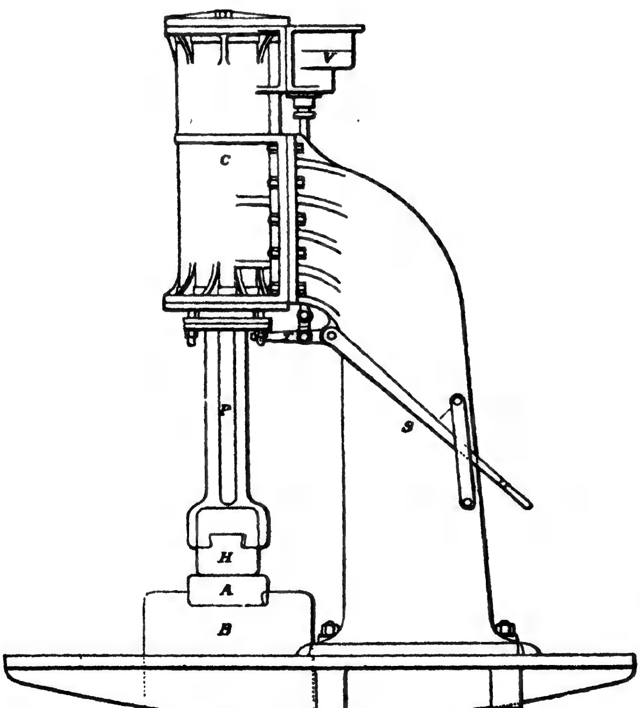
departure from all modes of forging that had ever been practised to the time, and constituted an original invention; one that has fully attested its value in actual service at Crewe, where such hammers have been at work for several years.

"It will seem probable that the arrangement of these double-acting hammers is necessarily complicated and expensive, but the contrary is the fact. The rams are simply two masses of iron mounted on wheels that run on tracks like a truck, and the impact of each hammer, so far as not absorbed in the work, is neutralized by the other. No shock or jar is communicated to framing or foundation, as in the case of single hammers that have fixed anvils. The same rule applies in the back stroke of the hammers, as the links that move them are connected together at the centre, where the power is applied at right angles to the line of the hammer movement. The links connecting the two hammers constitute, in effect, a toggle joint, the steam piston being attached when the links meet in the centre. The steam cylinder is set at some depth in the earth below the plane upon which the hammers move, and even when the heaviest work is done there is no perceptible jar to be felt when standing near the hammers, as there always is with those that have vertical movement and are single acting."

Besides the classes already mentioned, steam hammers are divided into single and double-acting hammers. In the single-acting hammers the steam is only employed to raise the tup or hammer head, which is then allowed to fall freely by its own weight; and the force of the blow struck is therefore only equal to the power developed by the given weight falling from the given height. In the double-acting hammers the steam is employed to accelerate the descent of the falling mass, as well as to raise the same; and as by this means the rapidity of the descent may be made to equal double that due to the action of gravity, and as the force of the blow struck by a falling mass increases as the square of the velocity, it follows that the power of a given hammer may by this means be increased three or four-fold; that is to say, a 5-ton hammer may be made to do work equal to that of a 15 or 20 ton single-acting hammer. Many hammers are now constructed to be used either as single or double acting, at the will of the operator.

Fig. 1385 is of a single standard 20-cwt. Rigby hammer by Davis and Primrose of Leith. This hammer is double acting, the cylinder C being 19 in. diameter with a stroke of 42 in. The piston with the piston rod P are forged in one piece from the best scrap iron, the lower end of the rod

1385.



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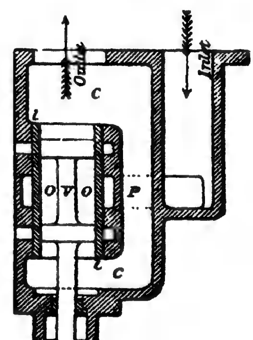
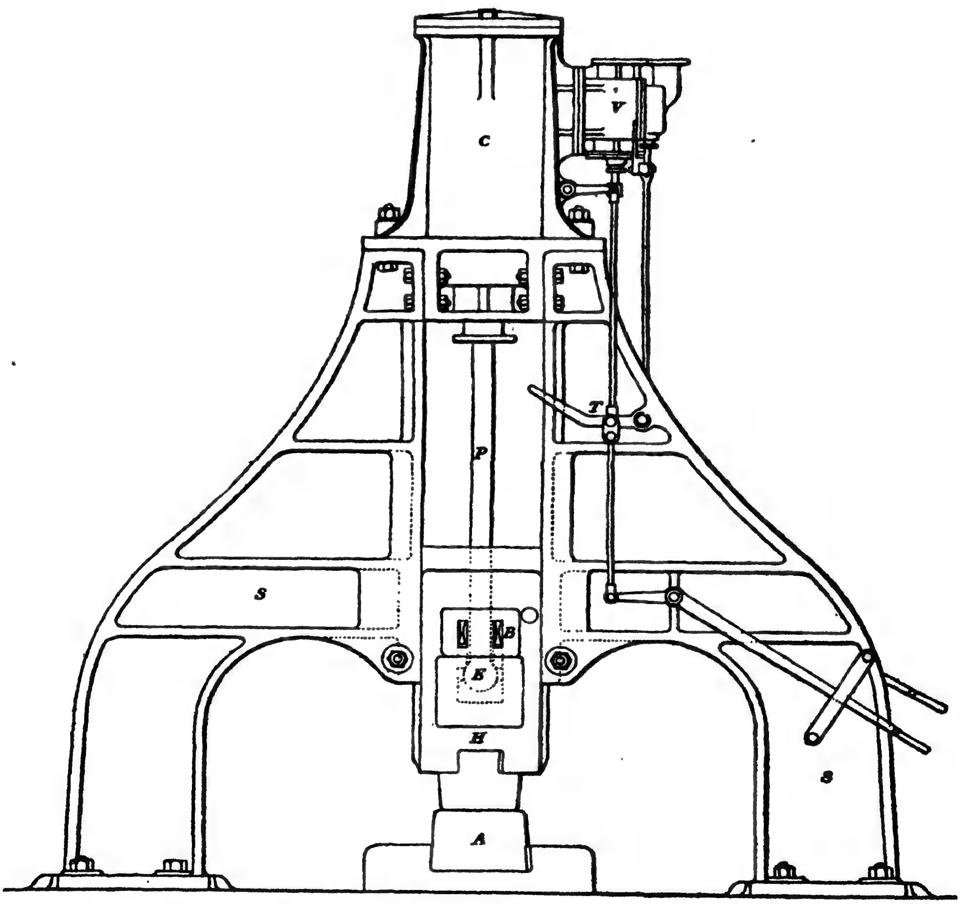


being enlarged and formed with a dovetail slot to receive the hammer face H which is made of steel. In consequence of this formation of the piston and rod it is necessary to make the stuffing box and gland of the cylinder in halves. The former is a tube of metal made to fit the interior of the cylinder and having a flange on the lower end by which it is bolted to the cylinder flange. The gland is of the usual kind, and the halves are held together by plates and bolts of malleable iron. The piston is fitted with Ramsbottom rings of steel. The valve V, which is a piston valve of wrought iron working in a brass-lined chamber, is shown in section in Fig. 1386, the lining *l* is pierced with holes opposite the ports for the passage of the steam. The steam enters the middle of the valve at *o*, between the two pistons, and according as the valve is moved up or down the steam enters the top or bottom of the cylinder,

and exhausts by the ends of the valve, a passage p connecting the lower and upper ends of the chamber C to take away the exhaust steam from the lower part. Connected to the valve spindle is a safety trigger T, the object of which is to prevent the piston from striking the upper end of the cylinder. When the hammer rises beyond a certain point the enlarged end of the piston rod strikes this trigger and raises the valve, thereby admitting steam to the top of the cylinder, exhausting from the bottom, and so reversing the motion of the hammer. In this hammer the weight of the moving parts, piston, piston rod, and tup, is a little over 20 cwt. The total weight of the hammer is about 18 tons, of which the anvil block weighs about 6 tons. The diameter of the piston rod is $9\frac{3}{8}$ in., and it is flattened on two opposite sides, the neck of stuffing box and the gland being similarly flattened, in order to prevent the piston from turning round when working. Generally in this style of hammer the area of the bottom side of the piston is about three-fourths of that of the top side. The pressure of steam used varies from about 35 lb. to 60 or 70 lb. on the square inch. These hammers are also made with double standards, the standards being of box section and placed 12 ft. apart at the ground level. The total weight of a double standard 3-ton hammer of this class, having a cylinder 25 in. in diameter and 5 ft. stroke, is about 46 tons, of which the anvil block weighs about 18 tons.

In Fig. 1387 is a 3-ton hammer made by Davis and Primrose, in which the standards are made so as to form guides for the hammer head. The cylinder C is 22 in. in diameter with a 4-ft. stroke; the valve being similar to that in Fig. 1386. The framing S is of H section, except for very heavy

1387.

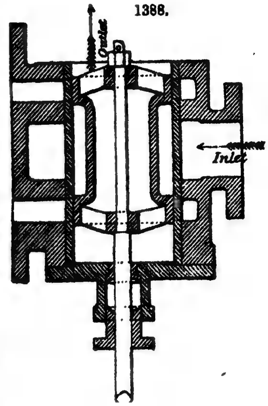


hammers, when it is made either of box section in cast iron, or of wrought iron. The piston and rod are forged in one piece from the best scrap iron; the piston being fitted with Ramsbottom rings of steel. The lower end of the rod is enlarged into a spherical form, as shown in dot at E, and into the tup is inserted a suitable cup to fit the spherical end of rod. The rod is held in its place in the tup by a cap B, formed in halves, which is hollowed out to fit the spherical end and is fixed by cotters. This arrangement provides against the side strains which are so frequently produced in the working of a steam hammer, as the tup can yield a little without unduly straining the piston rod.

Fig. 1388 is a section of the valve employed by Davis and Primrose for their self-acting hammers. This valve is of brass and hollow; it has two pistons. The steam entering at the middle of the

valve, between the two pistons, as in the hand-worked hammers, the exhaust from the under side of piston passing through the interior of the valve to the discharge pipe placed on the top. The self-acting motion is given by a suspension lever L of a curved form, which is kept in contact with the hammer face T, as in Fig. 1389. The tup T as it rises pushes this lever to one side and causes the valve to rise until the lower port opens to the exhaust and the upper port to the steam, when the hammer descends, and the valve then moves in a downward direction.

1388.



A double, single, and self-acting 10-cwt. steam hammer by Fawcett and Firth of Leeds, is shown in front elevation in Fig. 1390. The hammer is firmly bolted to a stone foundation; the anvil block B resting upon a distinct support, the upper part consisting of a double layer of balks which form an elastic cushion between the foundation and the anvil block. The weight of the anvil block is 5 tons, the total weight of the hammer, including the block, being 14·5 tons. The diameter of the cylinder C is 11½ in., and the full stroke of the piston 2 ft. The weight of the moving parts, 10 cwt., gives a total of 2240 units of work, which is equal to the force exerted by a weight of 1 ton falling through a height of 1 ft.; but by admitting the steam to the top side of the piston, and so accelerating its descent, the force of this blow may be considerably increased.

This hammer is so proportioned in the various parts, that all are equally strong, and in order to facilitate the carrying out of any necessary repairs the parts are made as accessible as possible; the repairing of a steam hammer generally occasioning

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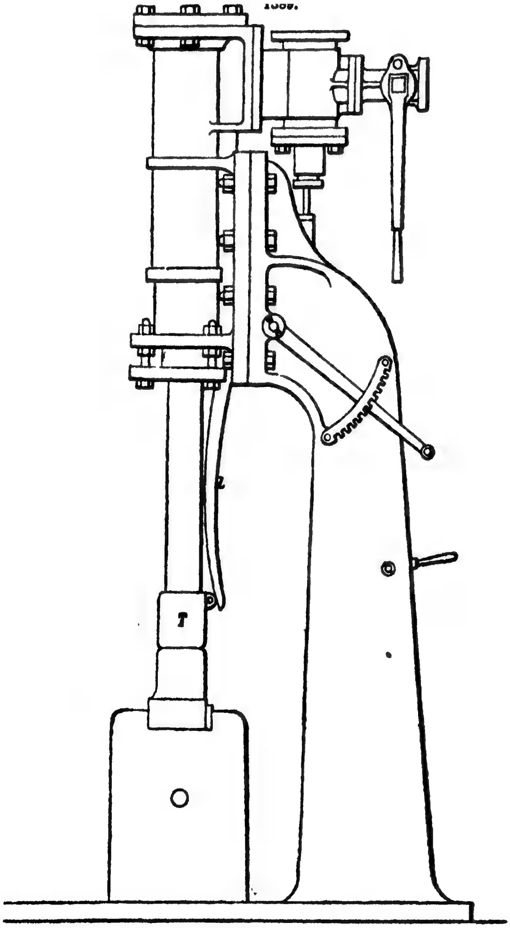

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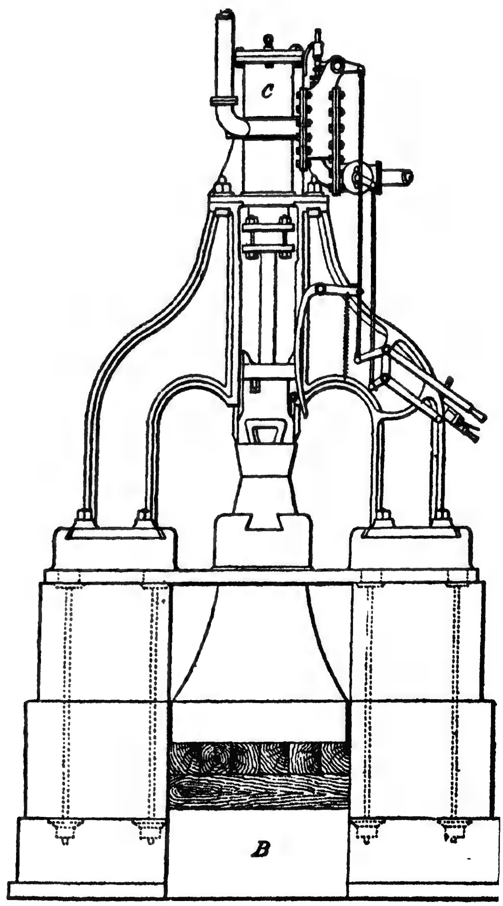

considerable expenditure, on account of the complex nature of its details, and the difficulty of getting at the various parts. One of the most important parts of all steam hammers is the valve, which is generally coupled direct and worked by hand, and it is therefore necessary that pressure

and friction should be as much as possible avoided; with a view to fulfilling these requirements, and at the same time rendering it easy to compensate for wear in either the valve or the cylinder face, the form adopted in this hammer consists of an equilibrium valve of a double V or square section, Figs. 1391 to 1395; Fig. 1391 is a sectional plan on the line *e f*, Fig. 1392, a sectional elevation on the line *a b*, Fig. 1393, a similar section on the line *c d*, and Figs. 1394, 1395, are a

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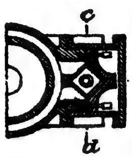

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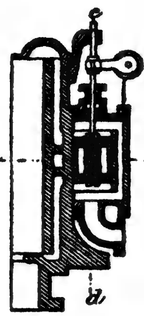

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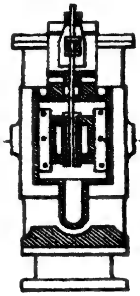

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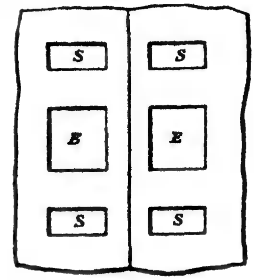
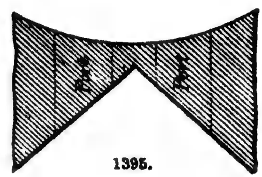




1395.

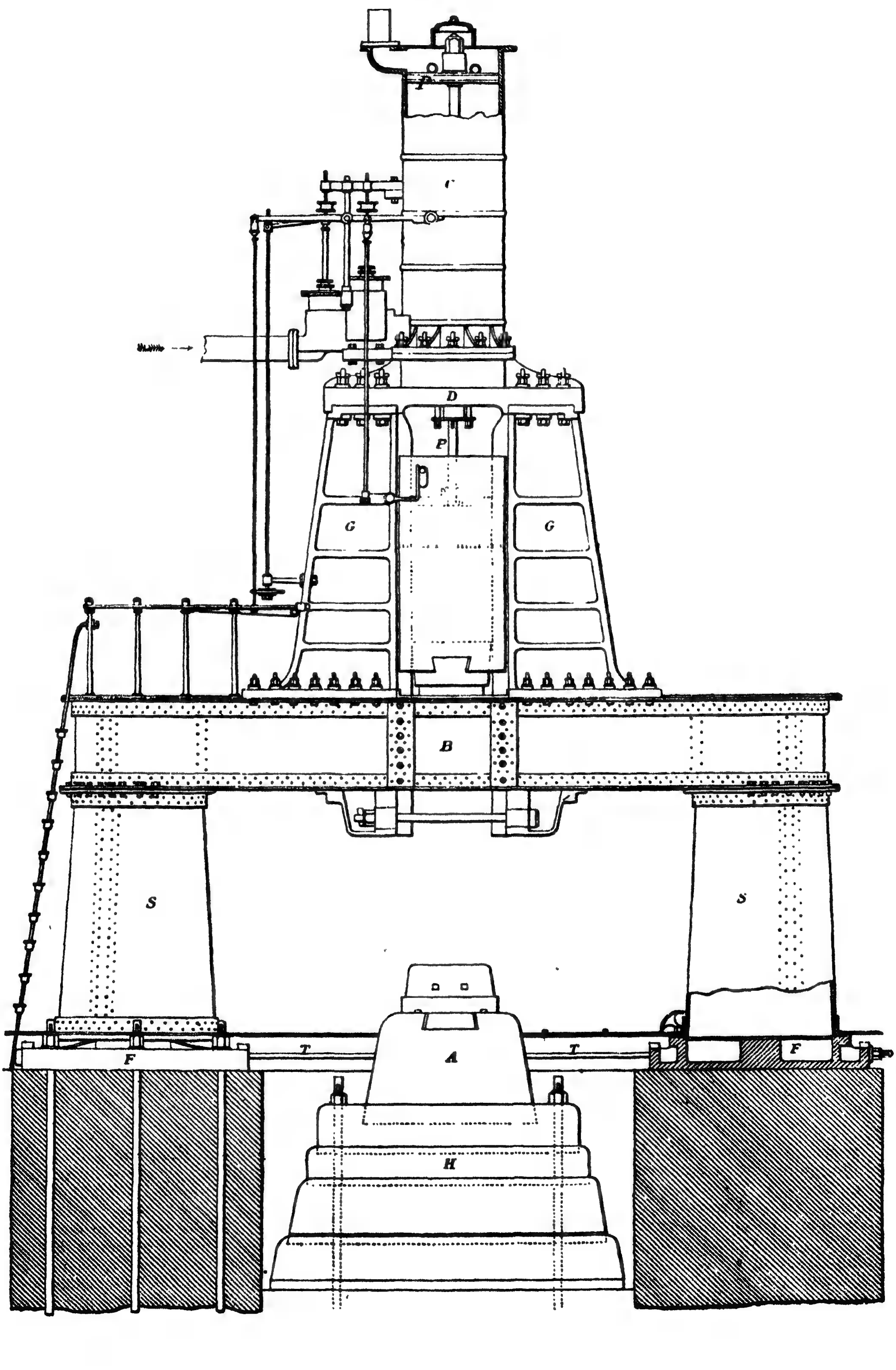
front view and section of a portion of the cylinder face showing the position of the ports, the central ports being the exhaust. This valve slides in a corresponding V face in the cylinder, and in a V jacket, by which the back part of the valve is enclosed; thus the only parts which are exposed to the pressure of the steam in the steam chest are the two ends; and as the areas of these are equal, the friction is reduced to a minimum. This form of valve admits of any wear, being easily adjusted; as in order to follow this up it is only necessary to plane up the jacket faces at H.

These hammers are made in various sizes, both as single and double standard hammers; and are either double and single acting, with dead blow by hand lever; or single and double acting worked by hand. In the former the valve is made without lap; in the latter lap is added to get the single action, and the valve travels more to get the double action, or steam at the top of the piston. The sizes of the single standard hammers range from ½ cwt. to 10 cwt.; and the double standard from 10 cwt. to 3 tons.

In Fig. 1396 is shown a 1500 kilo. steam hammer of German design. The framework of this hammer consists of two hollow wrought-iron standards S, slightly tapering, resting upon cast-iron bed plates F, which are held together by tie-rods T. These standards support a wrought-iron girder B, 3 ft. 1 in. in depth, on the top of which are bolted the cast-iron standards G, to which the bed plate D is bolted; this latter carries the cylinder C. The height of these standards with the bed plate is 9 ft. 9 in. The standards G, besides being firmly fixed to B by a number of bolts, also abut firmly against the covering plates of the girder, so that any lateral movement in the standards would necessitate the shearing of all the rivets which pass through the plates. The distance between the standards S, centre to centre, is 20 ft. 7 in., their height 8 ft. 6 in., and their mean diameter about 5 ft. The total height from the ground level to the top of the bed plate D is 21 ft. The diameter of the cylinder C is 3 ft. 7½ in., and the full stroke of the piston 8 ft. 3 in. The piston and piston rod P are made of the best crucible cast steel; the weight of the piston, piston rod, and tup being 14·75 tons, and this multiplied by the full stroke of the piston gives 272,580 units of work, equal to the power exerted by a weight of 121·6 tons falling from a height of 1 foot. The anvil block H is cast in four layers, and is firmly bolted to a separate foundation; the diameter of the bottom layer of this block is 12 ft., and the top layer 8 ft. 9 in., the height of the anvil A being 3 ft. 10 in. The weight of each of the wrought-iron columns S is 2 tons 9¼ cwt., the bed plates F, 6 tons 17¾ cwt., the girder B, 6 tons 8 cwt., each of the cast-iron standards G, 14 tons 5½ cwt., the bed plate D, 5 tons 8¼ cwt., and the cylinder C, 4 tons 18½ cwt.; the total weight of the whole structure, including the piston and tup, but excluding the anvil A and block H, being 86 tons 2¼ cwt.

In Fig. 1397 is shown a front elevation of the 35-ton steam hammer erected at Woolwich Arsenal in 1873. As this hammer is double acting, it can be rendered equal to a single-acting hammer having four times the length of stroke, or 42 ft., or to the same stroke with four times the weight, namely 140 tons, or about equal to a 150-ton single-acting hammer with a 10-ft. stroke. The standards S are of the ordinary H section, and are bolted to cast-iron box girders G bedded in concrete, these standards and girders being independent of the foundations of the anvil. The distance between the standards S is about 19 ft.; the height from the ground line to the top of the cylinder 45 ft.; and there is a clear height for forging purposes of 11 ft. The diameter of the cylinder C is 54 in., with a full stroke of 10 ft. 6 in. From the great weight and length of this cylinder, it was thought probable that if it were held only by the bottom flange, the vibrations caused by the violent concussions when the hammer is at work would crack the cylinder close to

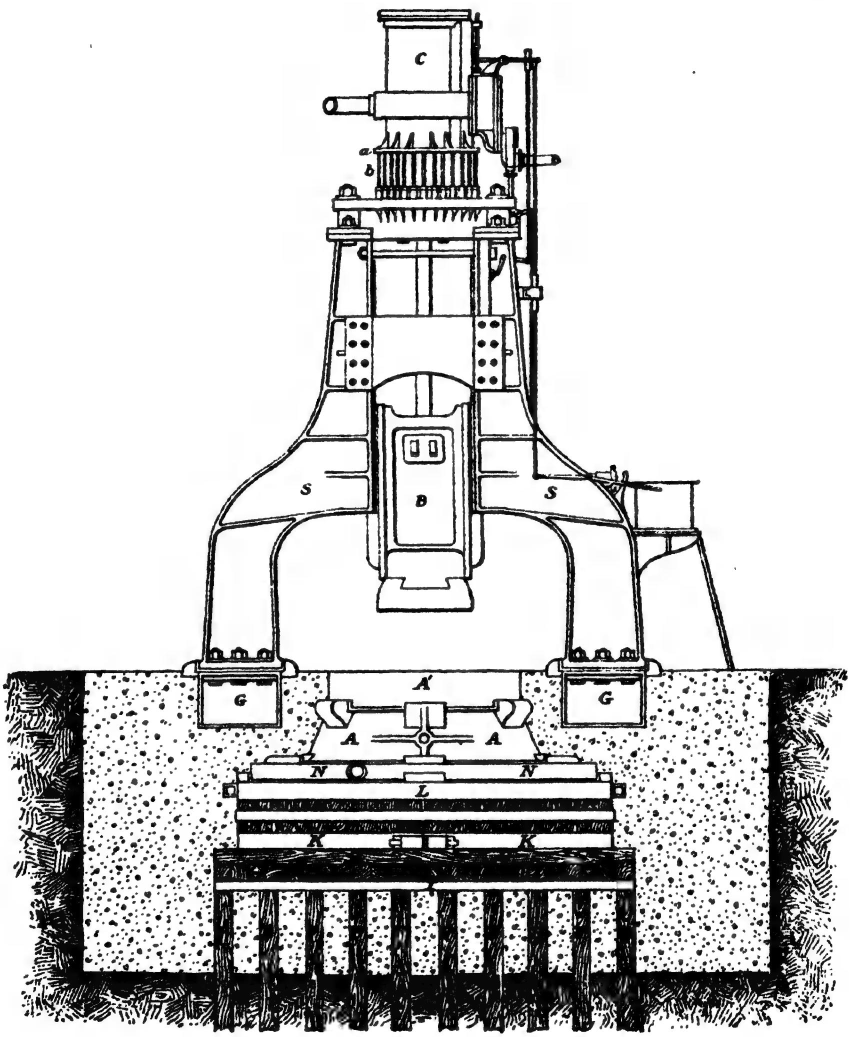
1396.



the bottom flange, an accident which has happened with smaller hammers; there is therefore provided a second flange *a*, at some distance from the bottom of the cylinder, and the long bolts *b*, from the entablature to this second flange, give a certain amount of elasticity to absorb the vibration. The valve is one of Wilson's balance valves, which is easily managed by one man, and can be regulated so as to admit the steam at the top of the piston or not, at the will of the attendant. The weight of the falling mass is 35 tons, the full length of fall being, as stated above, 10 ft. 6 in.; and in the hammer block B there is formed a well for the purpose of adjusting the distance of the block from the piston in the cylinder C, by which means the full amount of stroke can always be obtained, whatever may be the thickness of the work operated upon.

The ground upon which this hammer has been erected was at one time marsh land, and a large expenditure was necessary in order to secure a foundation which would be sufficiently solid, and at the same time elastic enough to withstand the impact of so great a mass. For this

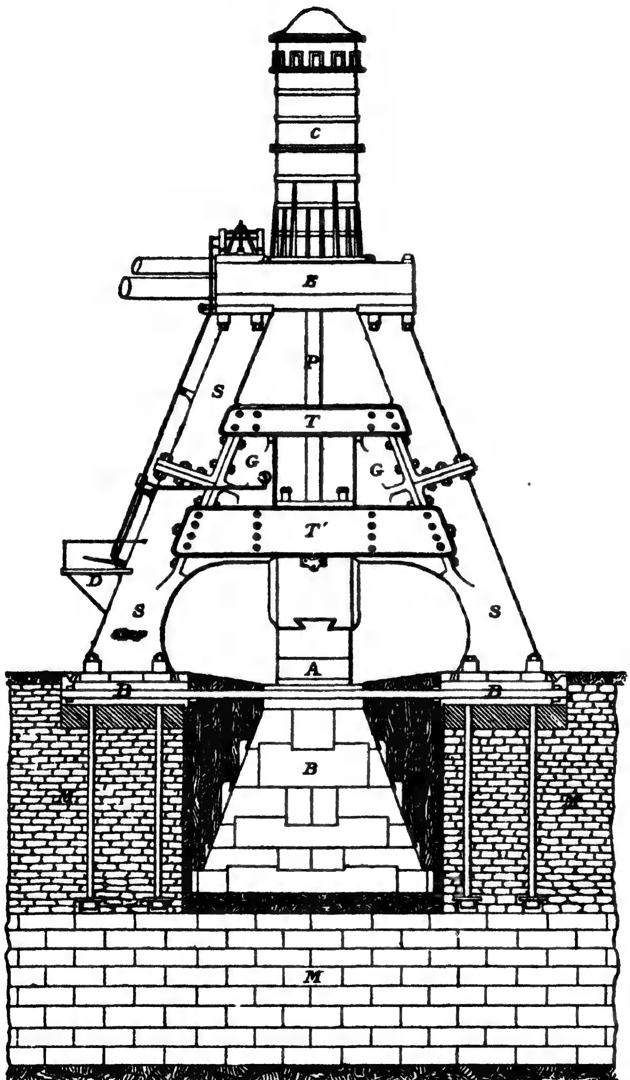
1397.



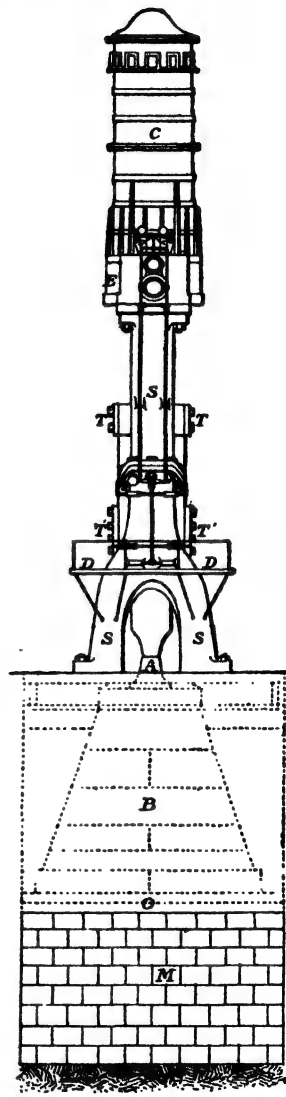
purpose the ground was excavated to a depth of nearly 20 ft. for a space of 42 ft. square, and in the centre of this hole one hundred piles P were driven in rows of ten, forming a square of 30 ft. on the side. These piles having been driven as far as they would go, were cut off level at a height of about 4 ft. 6 in. above the bottom of the hole; and the hole was then filled in with concrete up to the level of the tops of these piles. Upon the top of this was laid a cast-iron plate I, 30 ft. square and 11 in. thick, weighing 164 tons; this plate was cast in three pieces, for the purpose of rendering it less liable to accidents in transit. On the top of the plate I are two layers of oak balks, 12 in. square, upon which is a second cast-iron plate K, cast in two pieces, which weighs 121 tons, and is 27 ft. square by 11 in. thick. Upon this plate are oak balks M, 2 ft. long, placed on end, and fitted accurately together to form a solid mass, and which are held together by bands of iron 6 in. broad

and 2 in. thick. On these timbers is placed a third plate L, 24 ft. square and 12 in. thick, also cast in halves, and weighing 120 tons. Upon this is placed a thin layer of timber and felt, in order to fill up any inequalities or to make up for any want of flatness in the castings; and then comes a fourth plate N, 22 ft. square, 12 in. thick, and weighing 100 tons, which is cast in one solid piece. Upon the plate N is placed the anvil block A, which is a frustum of a cone 15 ft. in diameter at the base, 12 ft. diameter at the top, and weighing 103 tons; and upon this is placed the anvil A′, weighing 70 tons. It will thus be seen that the weight of cast iron in this foundation is nearly equal to 700 tons. The whole of the space around the foundation is filled in with concrete.

1398.



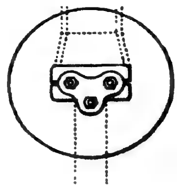
1399.



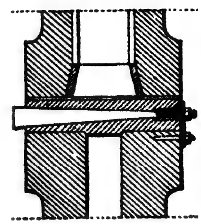
. 1398 to 1401 is shown the 8000 kilogramme steam hammer erected by Schneider of Creusot, which is the largest steam hammer in existence. Fig. 1398 is a front elevation, and section through the foundations; Fig. 1399 is a side elevation; and Figs. 1400, 1401, show the method employed for connecting the tup to the hammer block. The foundation for this hammer was excavated to a depth of about 36 ft. The first portion of the foundation consists of a mass of masonry in cement M, 18 ft. in thickness, and containing upwards of 785 cubic yards; on the top of this masonry is laid a bed of oak planks, O, 8 ft. 3 in. thick, to form an elastic cushion or seat for the anvil block B. This block is of cast iron, and consists of six layers, each of the layers, with the exception of the top one, on which the anvil A rests, being cast in two pieces; it is 18 ft. 4 in. in height, its area at the base being 355·2 sq. ft., and at the top 75·3 sq. ft.; the total weight of the anvil and

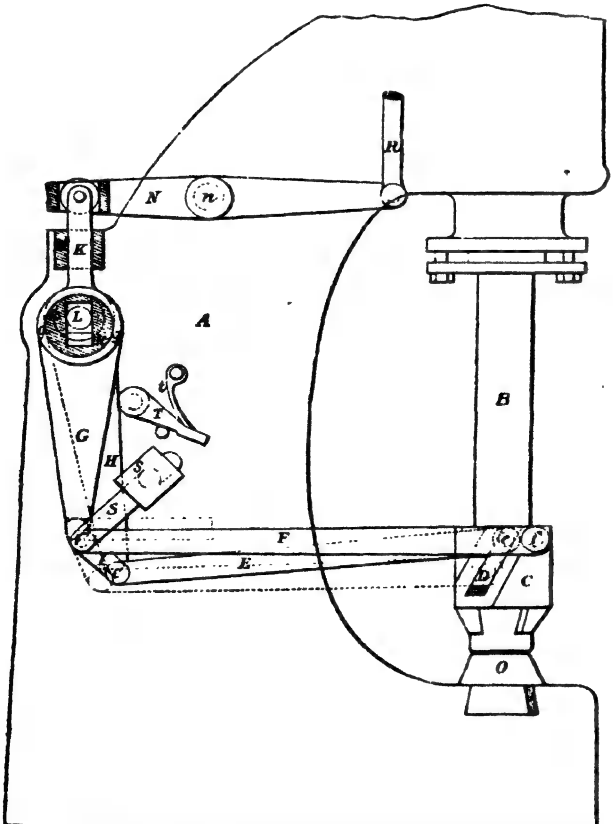
block being 736 tons 12 cwt. It will be seen that the anvil block rests upon the foundation entirely independent of the main supports of the hammer, the space between the foundations of the latter and the sides of the block being filled in with oak planking, as shown at O, Fig. 1398. The main supports S are rectangular in section; they are cast hollow, each one being formed in two pieces, and bolted together in the manner shown in the figures; they rest at the base on massive cast-iron bed plates B, to which they are keyed, the bed plates resting on the masonry M surrounding the anvil block. The guides G are cast separately, and are bolted to the supports S, as in Fig. 1398, the whole being firmly held together by the wrought-iron bracing plates T, which weigh 24·5 tons. The height of the main supports S is 33 ft. 7 in., and their weight, including the guides G, 245·5 tons. On the top of the standards S is fixed the entablature E, which supports the cylinder C, and this entablature weighs 29·5 tons. The cylinder C is made in two lengths, each 8 ft. 2 in. in height, the two parts being united by bolts; the internal diameter of the cylinder is 6 ft. 3 in., and the piston rod P 14 in. in diameter, the cylinder with its cover weighing 21·6 tons. The distribution of the steam within the cylinder is effected by means of two single equilibrium valves, the diameter of the admission valve being 13½ in., and that of the discharging valve 18 in.; these valves are operated by means of rods and levers, which are brought down to within the reach of an attendant standing upon the platform D, which is fixed at about 10 ft. above the level of the floor, and which affords a protection from the heat of the forging. The area of the under side of the piston, deducting that of the

1400.

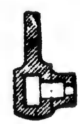


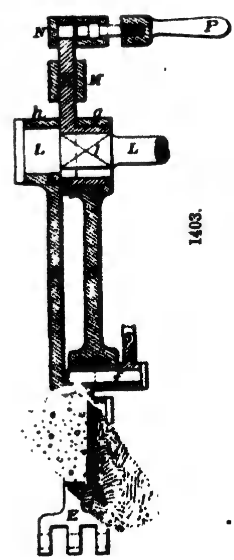
1401.





1405.





1403.

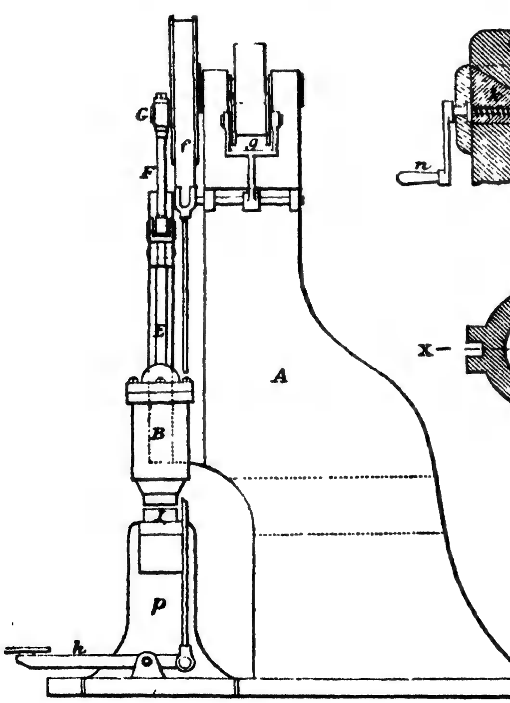
1404.

piston rod, is 4238 sq. in., which gives, with a pressure of 71 lb. per sq. in., a total lifting force of 134 tons. The weight of the falling mass, including piston, rod, tup, and all moving parts, is 79 tons, and this multiplied by the full stroke of the piston, namely 16 ft. 5 in., gives a total of 2,886,400 units of work, which is equal to the force exerted by a weight of 1247 tons falling through a height of 1 ft. The width between the supports S is 23 ft. 9 in., and the clear height under the lower connecting plates T is 10 ft. 6 in., so that there is ample room for the manipulation of the largest masses with

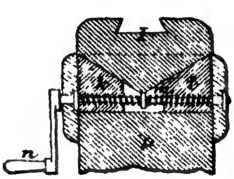
which the hammer may have to deal. The clear width between the tup guides G is 6 ft. 3 in. The height of this hammer from the bed plates B to the top of the cylinder C is 61 ft., and the height of the anvil block 18 ft. 4 in., which gives for the whole structure, including the thickness of the masonry foundation, a total height of over 92 ft. Notwithstanding this great height, which naturally tends to reduce the stability of the hammer, the whole has been so well proportioned, and the oak cushion beneath the anvil block acts with such efficiency, that rigidity has been secured, and the vibratory shock at a given distance is less severe than with many smaller hammers. The total weight of the whole of the parts from the bottom of the bed plates B to the top of the cylinder, including the moving parts and all parts necessary to the mechanism, is 520 tons 18 cwt., and this added to the weight of the anvil and block, namely 736 tons 12 cwt., gives a total weight of 1257·5 tons for the whole structure.

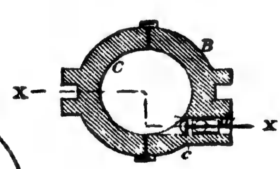
Sturgeon's valve gear for steam hammers is shown in Figs. 1402 to 1404. Fig. 1402 is a partial side elevation of a steam hammer indicating the position of, and the manner of connecting the valve levers; and Fig. 1403 is a vertical section through the levers. The gear renders the valve self-acting and regulating, so that it may adapt itself to all variations in the stroke caused by the varying thickness of the masses of metal upon which the hammer is required to operate. For this purpose the valve gear which is employed for reversing the valve for the up stroke, follows the hammer throughout the whole of its stroke, so as to be always in a proper position for reversing at the moment when the hammer strikes the object placed beneath it, the necessary motion being given to the valve by means of the jerk caused by the impact of the hammer. A is the hammer frame or standard, B the piston rod, and C the tup. In one of the sides of the tup C a slot D is formed to receive the stud *e* at the end of the link E, and to the same face of the tup the link F is connected by means of the stud *f*. The link E, at the end *e'*, is connected to the lever H, having a boss *h* working upon the plain part of the stud L. The lever H and the links E and F are all connected, by means of the short elbow link I, to a second lever G, as in Fig. 1403; Fig. 1404 being a plan of the end of the link E. The lever G is arranged so as to move through an arc and at the same time to admit of an up and down movement on its fulcrum L. Through the centre of the boss *g* passes a second boss *k* having a slot cut in it in order to allow an up and down motion upon the square part *l* of the stud L; the boss *k* being steadied and guided in its movement by the stem K working through the guide M. To the upper end of the stem K is con-

1406.



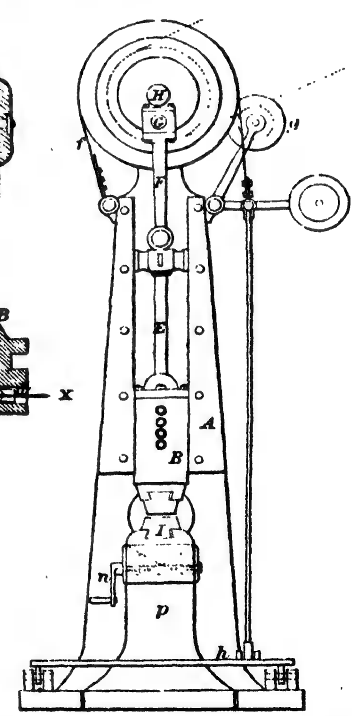
1411.





1408.

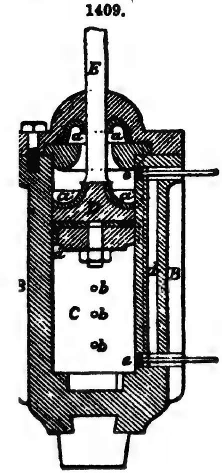
1407.



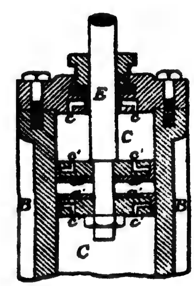
nected the rocking lever N, working upon the centre *n*, and to the opposite end of this lever the valve rod R is connected. When the hammer strikes the object on the anvil O, the shock caused by the impact forces the stud *e* forward in the slot D to the position shown by the dotted lines. This motion of the stud *e* and link E raises the lever G and stem K, and so depressing the valve rod R and reversing the valve; the hammer then commences its up stroke and continues to rise until, by the motion of the links and levers E F G H, the end of the rod S working through the guide *s*, is brought into contact with the stop T, this forces down the lever G and raises the stud *e* to its former position, thus again reversing the valve and causing the hammer to descend. The

stop T is held in position and caused to act upon the rod S by the spring *t*; and this arrangement allows the stop to accommodate itself sufficiently to the slight additional upward motion of the hammer which takes place after the reversing of the valve, such motion being due to the *vis viva* of the moving mass. In hammers having only a short stroke the stop T is fixed, but when it is requisite that the hammer shall admit of variations in the height of fall the stop is carried on an adjustable plate. When it is required to work the valve by hand or strike a dead blow, it is necessary to disconnect the rocking lever N from the other parts of the motion by drawing out the handle P, and thus allowing the stem K to work through the slot in the rocking lever N, Figs. 1403 and 1405. In this case also the stud *e* may be tightened in the slot D by means of a bolt.

1409.



Sholl's atmospheric hammer, Figs. 1406 to 1411. Fig. 1408 is a horizontal section through the cylinder or tup B; and Fig. 1409 is a vertical section of the same on the line *x x*. In this hammer the striking part B consists of a cylinder C with a piston D which is connected by means of the piston rod E and connecting rod F to the crank pin G; the cylinder C being filled with compressed air which forms an elastic connection between the striking part and the power by which it is operated. C is lined with lignum-vitæ or some other slow conductor of heat, in order that the heat generated by the compression of the air in the cylinder may not be communicated to the adjacent parts, and to prevent injury to the packing leathers of the stuffing box and piston; for similar reasons the piston D is made of the same non-conducting material. One of the principal features in this hammer consists in the stuffing-box leathers *a* and cylinder leathers *a'*; these are so arranged that the pressure of the air within C tends to force them into contact with the surface of the cylinder and of the piston rod, and by these means a perfectly air-tight joint is at all times secured. Fig. 1410 is of an alternative method of fitting the packing leathers *a* and *a'*; annular recesses are turned in the face of the piston and of the cylinder cover which are free to communicate with the interior of the cylinder by means of a number of small apertures *c* and *c'*; the compressed air passes through these apertures and so forces the leathers *a* and *a'* against the surface of the cylinder and of the piston rod. In the side of the cylinder C is formed an air-tight passage *d* which, by means of the valves *e* placed at the top and bottom, communicates with the interior; in the side of the cylinder are also formed a number of small apertures *b* which are opened and closed by valves. These valves may be opened or closed at pleasure, and are arranged to be actuated by the cylinder in its reciprocating motion, their object being to regulate the force of the blow struck by the hammer. The driving power is a belt, its action being regulated by means of the steel friction brake *f*, which is actuated simultaneously with the belt tightener by the treadle *h*; and by this arrangement the hammer may be made to deliver blows with any desired force or rapidity, or to give a dead blow. In conjunction with this hammer, a special construction of anvil, Fig. 1411, is employed. The anvil block I can be raised or lowered at pleasure by means of the wedge pieces *k* and *l*, which are caused to approach or recede from each other by the right and left handed screw *m*. The principal object of this arrangement is to allow of the hammer delivering any number of light blows with great rapidity.

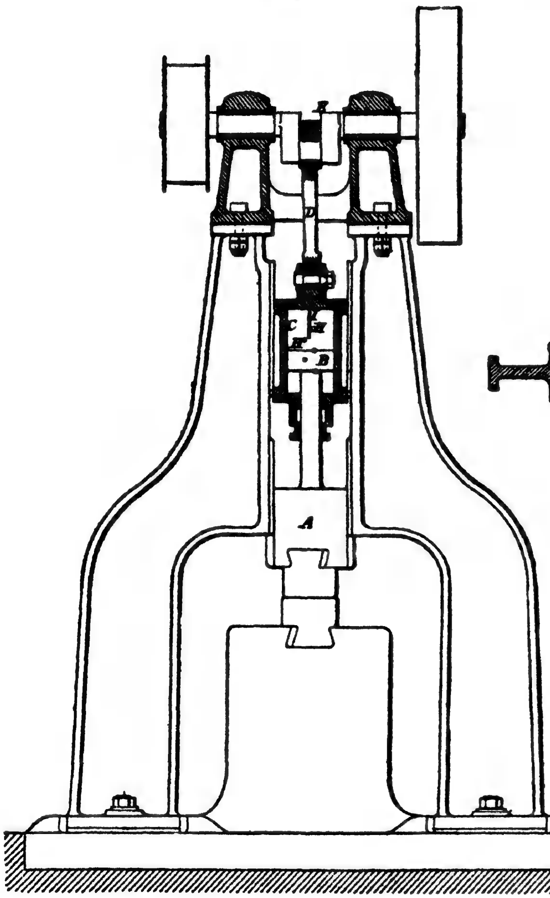


1410.

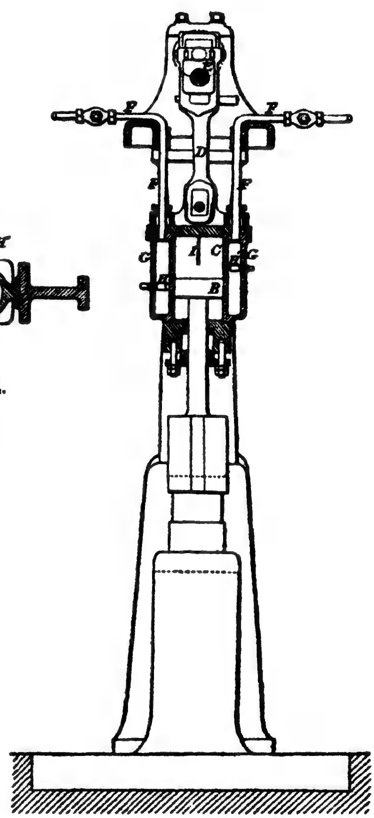
David Davy's power hammer, Figs. 1412 to 1414. Fig. 1412 is a front elevation partially in section, Fig. 1413 is a vertical cross section, and Fig. 1414 a horizontal section through the cylinder C and framing. In general structural appearance this hammer is very similar to the ordinary pneumatic hammer; the tup A being attached to a piston B working in a cylinder C, connected to a crank shaft E, from which it receives its motion in the usual way. The construction of the cylinder, however, differs considerably from others. In pneumatic hammers as usually constructed the air is admitted to the cylinder C at atmospheric pressure, the compression above and beneath the piston necessary to raise the hammer and to accelerate its fall, being effected within the cylinder itself, and consequently the construction of a very powerful hammer on this principle is almost impracticable, on account of the large capacity which would be required in the cylinder; but in this hammer the air is introduced into the cylinder at a higher pressure than that of the atmosphere, and increased according to the power required. Steam may be employed to take the place of compressed air in the cylinder C, but in that case provision must be made for carrying off the water of condensation. It is claimed for this hammer that by supplying the air to the cylinder C at a pressure exceeding that of the atmosphere, the power of the hammer is increased to a corresponding degree; and that consequently under this system very powerful hammers may be constructed without increasing the dimensions of the cylinder C as would otherwise be required. On each side of C is a pipe F for conveying the compressed air from the accumulator R, Fig. 1415, to its interior; the portions F' of these pipes are parallel to the sides of the cylinder C, and pass through stuffing boxes at the top of the chambers G situate on each side; the cylinder in its reciprocating motion slides up and down the pipes F', and so maintains a constant connection between the supply pipes F and chambers G. The chambers G communicate with the interior of the cylinder C by means of the holes H which are placed so as to be immediately above and below the piston B, when the latter is at the centre of its stroke; and these holes are fitted with screw plugs H' by which any of them may be closed, in order to regulate the amount of extra compression which shall take place in the cylinder C in the ordinary way. On the

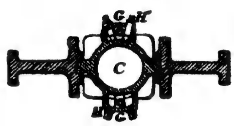
inside of the cylinder C there are longitudinal relief channels I for the purpose of allowing the compressed air to pass from the upper to the lower side of the piston B, when the latter passes beyond the ends of the channels, and so to restore the equilibrium within C. Fig. 1415 is a section through the apparatus employed for supplying the compressed air to the cylinder C. The cylinder of the air pump M, with its section and delivery valves N O, are placed within the closed chamber P, which is filled with water to above the level of the opening Q, the water being poured into the cistern at the siphon trap Q′, through which also is drawn the supply of air to the suction valve N; the object of this arrangement being to purify and cool the air before compressing it. The bottom of the accumulator chamber R′ is also made to dip into the water in the cistern P for the purpose of keeping cool the compressed air contained therein. The accumulator ram R is loaded with weights in the usual way in order to obtain the required pressure

1412.



1413.





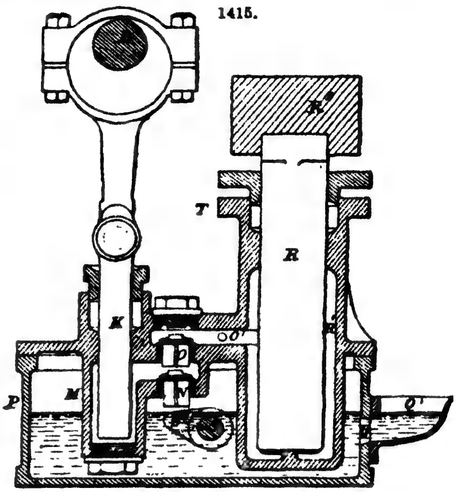
1414.

within the chamber R′ and cylinder C. The pump plunger K is worked from an eccentric on the shaft L. To obviate the necessity for stopping the plunger K each time that the accumulator cylinder is sufficiently charged, the following means are adopted. A rocking shaft S is mounted in the cistern P, and is provided with a cam or lever arm S′ so placed as to be capable of lifting the suction valve N off its seat and supporting it in that position. One end of the shaft S is prolonged through the side of the cistern P, and is provided with a lever arm and a connecting rod T, thus causing the shaft S to revolve and the cam S′ to raise the suction valve N from its seat, so that the plunger K will continue to oscillate without supplying any air to the accumulator R′. Directly the quantity of air within the accumulator R′ is reduced and the ram R descends, the rod T will drop and allow the cam S′ and valve N to return to their former positions, and the pump will again commence to deliver air to the accumulator R′.

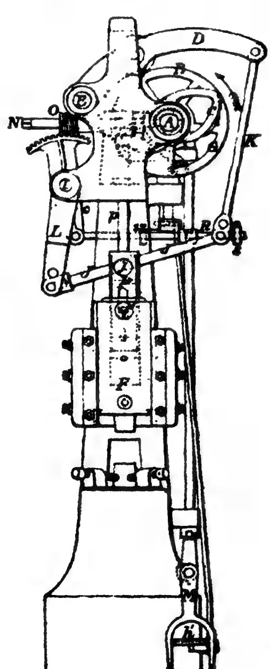
Longworth's pneumatic hammer, of which Figs. 1416 and 1417 are front and side elevations, is so complicated in the details of its construction, that it is very questionable if it can afford satisfactory results in working, as among so much complication of parts there must of necessity be liability to derangement; at the same time the manner of constructing the cylinder, which does away with the necessity for the use of packing, must be an improvement of much practical value if found to work satisfactorily. The peculiarities in the construction, and the manner of actuating this hammer [illegible], however, be readily understood from the following description. The horizontal shaft A is

provided with fast and loose pulleys $a\,a'$, and is driven by a belt. The shaft A for a portion of its length, is made square in section, and on this square part the two cams B and C are loosely fitted, so as to partake of the rotary motion of the shaft, and at the same time be free to slide upon it. On the shaft E, which is parallel to A, is fixed the rocking lever D, and to this a reciprocating motion is given by the action of the cams B and C upon the rollers b and c, these rollers being fixed to D; and this motion of the rocking lever is communicated to the hammer F, the cam B acting upon the roller b lifting the hammer, while its downward stroke is accelerated by the action of the cam C upon the roller c. In order to do away with the necessity for packing glands to the air cylinder of the tup, the same is constructed as in the section, Fig. 1417. The main or outer cylinder F, which forms the tup, slides in V-shaped guides in the framing of the machine, and has working in it the piston P, this being formed with an internal cylinder to receive the secondary piston f, this latter piston being attached to the main hammer F, by a pin f' which passes through slots in the piston P; through the upper part of the piston P passes the pin j, which forms with the lever J the means of connection between the rocking lever D and hammer F; and into the top of the piston P is screwed a guide rod p, which works through a part of the framing. The action of these pistons and cylinders is as follows;—When the piston P is forced down, a cushion of compressed air is formed between the bottom of it and the interior of the main cylinder F; and when the piston P is raised a similar cushion is formed between its interior and the bottom of the piston f; the air for this purpose entering through holes or ports formed in the side of the main cylinder F, Fig. 1417. To the boss of the rising cam B is fixed a circular disc G, the radius of which is equal to the largest radius of the rising cam. When the hammer is required to remain at rest, the disc G is in the position in Fig. 1417, when it supports the roller b, and with it the rocking shaft D, the shaft A revolving without imparting any motion to the rocking lever. On the side of the disc G

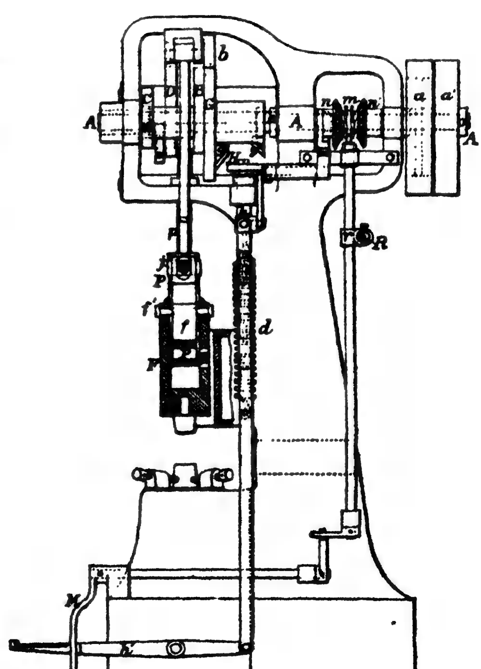
1415.



1416.

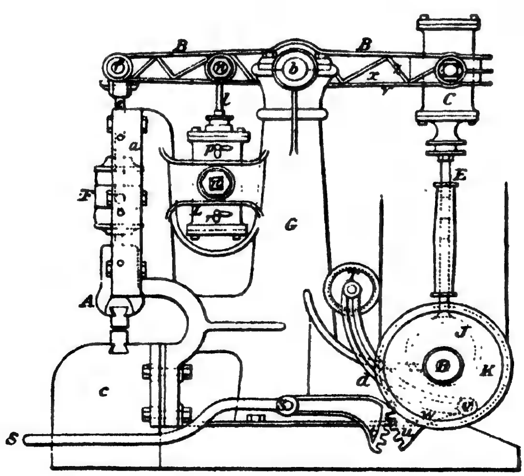


1417.



there is an inclined cam g, and on the boss of the disc a similar cam g'; these cams are situate in different planes, and are inclined in opposite directions. Below the shaft A and between the cams $g\,g'$ is a horizontal disengaging roller H mounted upon a vertical rod h, which is connected to the foot lever

h'; the roller H being held in its normal or depressed position by means of the spring d, the lower end of which is connected to the framing, and its upper end to the rod h. By pressing down the lever h' the roller H is brought into the plane of the cam g', and by its action causes the cams B C and disc G, with their connecting bosses, to slide upon A towards the right hand, which brings the cams B and C into the planes of the rollers b and c. The rotation of the shaft A will now cause B and C alternately to depress and raise the hammer; and this action will continue so long as the lever h' is held down, so that a single blow or any number of blows may be struck by the hammer as required. Directly the lever h' is released the spring d draws down the roller H into the plane of the cam g, the action of the roller upon the cam g causing the cams B and C and disc G to slide in the contrary direction, or toward the left hand, which brings the various parts into the position Fig. 1417; and so arrests the motion of the hammer by the action of the disc G. Upon the shaft A are two collars $e\ e'$, which fit into recesses formed in the bosses of the cams B C, and act as air pistons to check the momentum of the cams when sliding on the shaft for the purpose of putting the hammer in or out of gear; there is also an arrangement, shown in Fig. 1417, for preventing the roller H from being forced out of the plane of the inclined cams $g\ g'$ while acting upon them. The distance to which the hammer is raised or depressed, and consequently the force of the blow, is controlled and regulated as follows. The connection between the rocking lever D and hammer F is formed by means of the lever J, which is circular in cross section; and this lever slides freely through the pin j, in the upper part of the piston p. One end of the lever J is connected to the rocking lever D by the connecting rod K, and the opposite end is pivoted on a movable fulcrum on the hanging arm L, which is fixed to a sector shaft l carried by the main framing; and according as this fulcrum is moved to the right or left hand, relative to the connecting pin j, a greater or less movement will be given to the hammer F. To control the movement of this fulcrum, a forked lever M is connected by a series of shafts and levers to a clutch m on the shaft A; the clutch being so connected to the shaft as to revolve with it, and at the same time being free to slide upon it. The clutch m is situate between two bevel wheels $n\ n'$, mounted loosely on A, each of these wheels being formed with a clutch on its surface. The wheels $n\ n'$ both gear with a pinion on the shaft N carrying a worm O which gears into a toothed sector o on the sector shaft l. When the forked lever M is moved to the right or to the left the clutch m is brought into driving contact with one or other of the bevel wheels $n\ n'$, causing the shaft N and worm O to revolve, and so moving the sector o and sector shaft l, to which is fixed the arm L; this, according as the sector is moved in the one direction or the other, increases or decreases the length of the lever J on the side K, thereby increasing or shortening the distance through which the hammer F is raised and lowered, and so causing a heavy or light blow to be struck as required. To the lower arm of the toothed sector o is pivoted a rod R sliding freely in the guide r, and carrying two adjustable stop-collars $s\ s'$. When the toothed sector o is moved in either direction the collar s or s' comes in contact with the arm r on the clutch shaft, and throws the clutch m out of gear with the bevel pinion o or p as the case may be, and prevents any further motion of the arm L. The connecting rod K and fulcrum arm L are each provided with more than one hole, so that the hammer F can be raised or lowered bodily, to admit of greater variation in the thickness of the work operated upon.



1419.

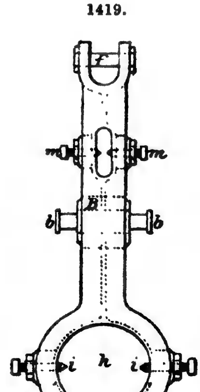
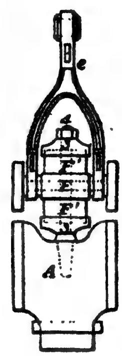


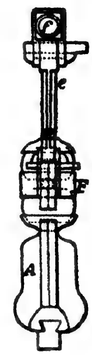
Fig. 1418 is a side elevation of Butterfield's atmospheric hammer. The main frame of the hammer G is provided at the top with plummer blocks to support the journals b of the hammer beam B, of which Fig. 1419 is a plan. This beam is of cast iron, in one piece, in the form of a truss, having a central longitudinal web x with flanges and ribs $y\ z$ on each side of it; the journals b being situate at about midway of its length. To the forward end of the beam B is attached the hammer A, which is connected to the hammer beam by the forked rod end e. Between the cross-head F and cups 3, Figs. 1422, 1423, are fitted solid indiarubber cushions F'; these cushions are provided with a central hole to allow of the passage of the rod 4, and they are finally held at a proper tension between the cross-head and cups by means of a tightening nut screwing upon the rod 4. The

cushions F′ allow to the hammer A an easy movement, preventing shock and concussion, and relieving the hammer rod from much of the resistance due to the rebound. In the circular loop *h* at the back end of the beam B is suspended the air cylinder C, Fig. 1418, which is free to oscillate upon the screws *i* by which it is supported. C is closed at both ends, the piston rod E passes through a stuffing box, and is connected to the rod of the eccentric J. In the side, at about midway of its length, there is a small hole forming a communication between the external air and the interior of the cylinder. The eccentric J is made with a central slot to allow of its being adjusted to give a greater or less throw, in order to obtain any required length of stroke of the piston D; and this eccentric after being adjusted is firmly secured upon the shaft H by means of a nut turning upon the shaft and a set screw passing through the collar, as in the section Fig. 1420. Between the hammer A and main standard G is suspended the supplemental cylinder L, shown in section Fig. 1421, the piston rod *l* is connected to the hammer beam by means of the centre screws *m*, the cylinder itself being so suspended on its centres *n* as to be free to oscillate backwards and forwards in conformity with the up and down motion of the beam B. The diameter of the cylinder L is less than that of the cylinder C; and the length or thickness of the piston P is nearly equal to half the length of the interior of the cylinder. In the side of L, and about midway of its length, are two small holes *q*, forming a communication between the external air and the interior of the cylinder; and at the top and bottom of the cylinder, and communicating with the interior, are two cocks *p* and *v*.

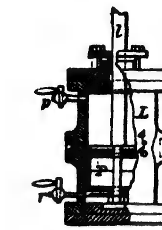
1422.

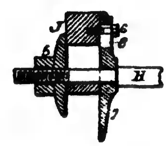


1423.



1421.





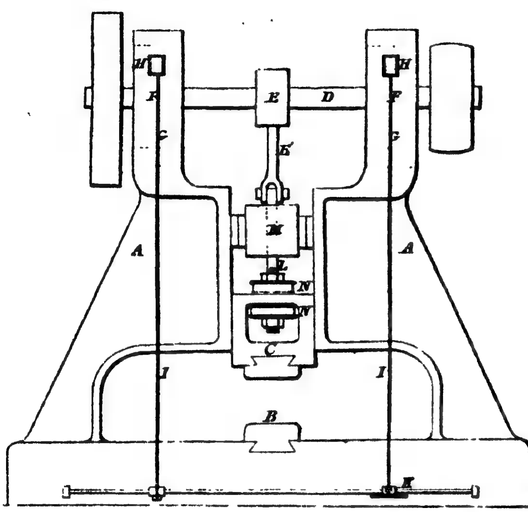
1420.

This hammer is constructed to be driven by the power obtained from a belt applied to the pulley K, on the shaft of which is fixed the eccentric J; the shaft H being supported in plummer blocks which are fixed to the projecting arm *d* of the main framing G. The treadle S and tightener T are for starting, stopping, and regulating the speed of the hammer. The treadle S, Fig. 1418, is pivoted upon pins which are fixed in the sides of the framing; on the side where the belt pulley K is fixed the end of this treadle has a segmental rack *t* gearing into a similar rack *u* on the front of the tightener arm U, pivoted upon the pin *v*, which is fixed in the side of the arm *d*; on the under side of this arm is a projecting shoe *w*, which extends within the rim of the pulley K, and this shoe, when the treadle is released and the tightener falls away from the belt, acts as a brake upon the pulley, and so arrests the motion of the driving shaft H; on the opposite side of the framing the end *t′* of the treadle S is formed to act simply as a counterweight. The cylinder C with its attachments is constructed to equal the weight of the hammer A and its attachments, thus balancing the beam B upon its journals *b*; and, consequently, the power required to work this hammer is small, being only so much as is necessary to overcome the inertia and friction of the parts.

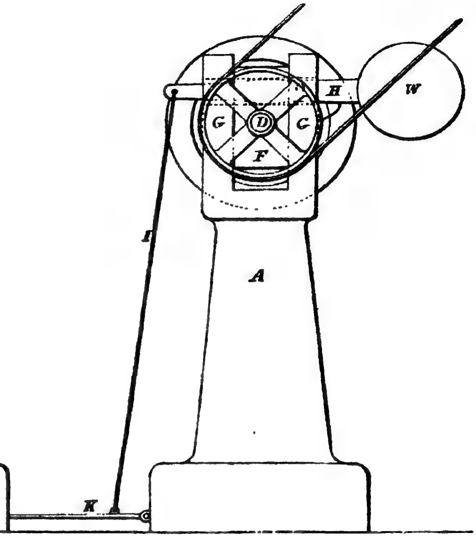
When the piston D, by the revolution of the eccentric J, is caused to descend, the compression of the air in the lower part of the cylinder C commences immediately that the piston has passed the opening *k*, and directly the power developed by this compression is sufficient to overcome the inertia and friction of the moving parts the cylinder C is drawn down, and the hammer A begins to rise; when the eccentric arrives at the bottom of its throw, and the movement of the piston is reversed, the hammer A will continue to rise under the combined influence of the power developed by the expansion of the air in the bottom of the cylinder C and the momentum which it has acquired from the downward stroke of the piston, until the power developed by the compression of the air in the upper portion of the cylinder is sufficient to overcome these two forces, when the hammer will be driven down upon the anvil R, the force of the blow being in proportion to the rate of reciprocation of the piston D. While the eccentric J is passing over its lower dead centre the piston D, with its rod and connections E, is supported by the compressed air in the bottom of the cylinder, and thus the eccentric is relieved of all thrust while reversing the motion of the rod and piston; and the same relief is accomplished while the eccentric is passing its upper dead centre by the action of the compressed air in the upper part of the cylinder. This arrangement possesses, however, the disadvantage of causing an upward thrust upon the bearings *b*, consequent upon the continued upward movement of the hammer, after the reversing of the rod E; and it is for the purpose of counteracting this strain that the intermediate cylinder L is employed. The motion of the piston P is contrary to that of the piston D, and consequently when the cylinder C descends, the piston P is drawn to the top of L, and the tension of the compressed air therein is opposed to the downward motion C; and by the proper balancing of these opposing forces all upward thrust of the journals *b* is prevented, the hammer beam B working smoothly without any jar or shock. The regulating of these forces is accomplished by means of the cock *p*, by the opening or closing of which a greater or less escape of the compressed air will take place from the upper part of the cylinder L. The piston D passes its vent *k* at midway of its stroke; but the piston P cuts off its vent *q* almost immediately that it begins to move, so that the amount of compression obtained in the cylinder L will be about double that in the cylinder C; this allows of a corresponding adjustment of the valve *p*. It is a matter of great importance in hammers of this class to be able to vary the power of the blow without altering the speed, and this is effected in this hammer by means of the valve *r*, which is placed at the bottom of the cylinder L. When *r* is closed, the air which is compressed under the piston P absorbs the force exerted by the downward stroke of the hammer, without in any way affecting its speed.

Alfred Davy's power hammer is shown in Figs. 1424 to 1426; Fig. 1424 is a front elevation, Fig. 1425 a side elevation, and Fig. 1426 an enlarged view of the tup and its connections. The shaft D is so arranged as to be capable of being raised bodily, so as to increase the distance between the face of the tup C and of the anvil B; by which means the hammer may be caused to give any number of light or heavy blows without interfering with its speed, or it may be so far raised as to be free to oscillate without giving any blow. At the upper part of the standards A are two guides G,

1424.



1425.



between which are placed the bearing blocks F, which carry the shaft D; the blocks F being free to slide up and down between the guides G. To the rear guides are pivoted the levers H, which pass through slots in G. At the back of these levers are fixed weights W sufficiently heavy to counterbalance and lift the hammer tup C and shaft D with their connections, and at their forward ends the levers are connected by means of the rods I to the treadle K. The parts H, which pass through the guides G, are slightly rounded on their lower and upper edges. When the hammer is out of gear, the levers H cause the blocks F to rise in the guides by the action of the counterweights W; and thus lift the driving shaft D, and with it the tup C, so that the latter will continue to oscillate without striking the face of the anvil. By pressing down the treadle K, C will strike the object placed beneath it, the force of the blow being in proportion to the extent that the treadle K is depressed; the farther the latter is pressed down the heavier being the blow delivered by the tup, and conversely. The tup C, made of cast steel, has an opening *c* extending from front to back. Through the upper part passes the spindle L, on which are fixed the two rubber cushions N N', supported in their proper position by metal discs and nuts screwing on the spindle L; the distance apart of the cushions being so regulated as to give that amount of play between them and the part of the tup which they embrace, which is best suited to the size of the work being operated upon. The spindle L passes through the guide M, bolted to the standard A, and is connected to the eccentric rod E'. The cushions prevent or minimise the shock to the driving shaft and other working parts of the hammer, and the play between them and the tup serves to accommodate the hammer to work varying in size within certain limits; sufficient play being always allowed to permit of the tup falling entirely independent of its connections, so that the force of the blow is due solely to the velocity and weight of the tup, and is not either accelerated or retarded, by the indiarubber cushions, at the instant the work is struck.

1426.

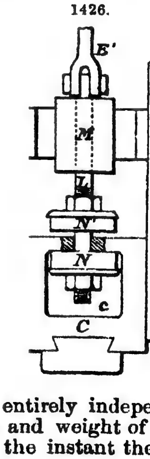
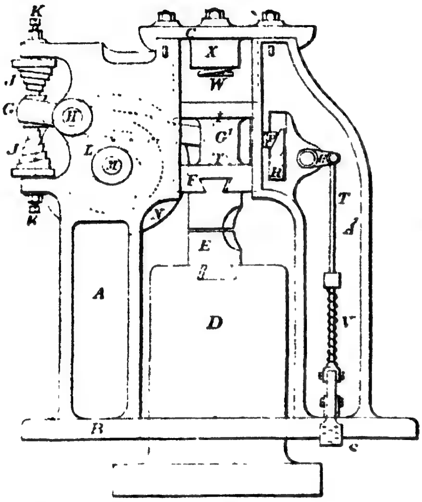


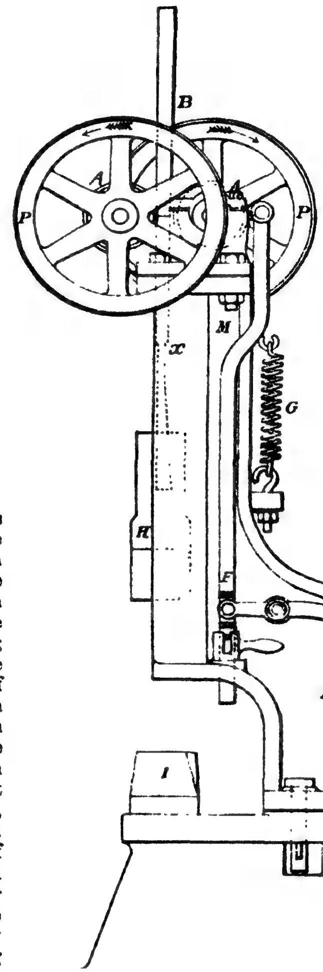
Fig 1427 is a front elevation of Glossop's hammer. The power is applied to a pulley on the shaft of the flywheel N by a belt, the hammer being lifted by means of the cams L which are fixed to the shaft M. The frame A is of cast iron, secured to the base plate B, and is further secured by means of the cap C. D is the anvil block supporting the anvil E. The tup F is supported by the lever G, having its fulcrum at H. The end G' of this lever is made of a circular form; the opposite or shorter end of the lever is acted upon by the springs J, the tension of which can be regulated by means of the screws K; the object of these springs being to balance the weight of the tup F, and so reduce the work of the cams to a minimum. The rounded end G' of the lever G bears on two removable blocks I, which are let into recesses in the tup F, so that the lifting action of the lever is always in a line perpendicular to the axis of the tup. On the sides of the

tup are guide strips O, which work in grooves formed in the standards A; P and P′ are two friction blocks, having a spring between them, and R is a wedge-shaped slide which is raised and lowered by means of the treadle S acting through the rod T and lever U, the wedge R being forced upwards and held at its highest position by the action of the spring V on the rod T; and when the wedge is in this position, the lever G is supported out of reach of the cams L, so that the shaft M may continue to revolve without causing the hammer to act. On the under side of the cap C is a box X, in which is secured a strong rubber or steel spring W. When the hammer

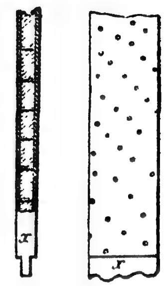
1427.



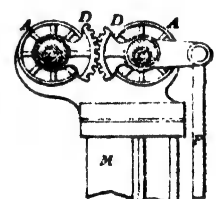
1428.



1429.



1430.



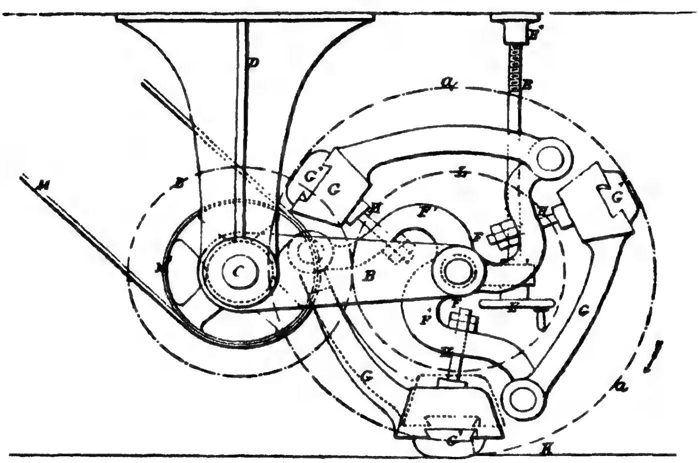
is in gear, the tup is propelled against this spring by the action of the cams L on the lever G, causing the tup to descend with a much greater force than it otherwise would. The motive power having been applied to the pulley on the shaft M the latter will revolve, and with it the cams L; the workman then presses down the treadle S which releases the tup, the revolution of the cam L then lifts the lever G and with it the tup F, and when the point of the cam passes the projection on the lever G the tup drops; the speed, however, at which the lever is lifted by the cam propels it considerably higher than the cam itself, and causes the tup to strike against and compress the spring W, the reaction of which accelerates the fall of the tup, and increases the power of the blow. In order to obtain a lighter blow the pressure of the operator's foot on the treadle S is partially withdrawn, and the action of the spring V on the friction blocks causes a pressure on the long strip O, thus retarding the action of the tup; and when the pressure of the foot is entirely withdrawn from the treadle, the tup will be caught at its highest point, and held by the friction blocks suspended out of reach of the action of the cam I until pressure on the treadle again releases it.

Hasse's friction forge hammer, shown in side elevation in Fig. 1428, differs considerably in its mode of action from those already described, resembling somewhat that of a pile driver. At the top of the main framing M are two friction rollers A, the axes of which revolve in eccentric bearings C, to which are connected the segmental racks D gearing into each other. By raising or lowering the rod F, by means of the lever arm E, the axes C are brought nearer to or more distant from each other; the arm E being so balanced by the action of the spring G, which is attached to the rod F and to a part of the main framing M, that this lever E will remain suspended in the position in which it may be at the moment when released by the workman. In order to ensure, as much as possible, the uniform rotation of the friction rollers A, each of the axes C is provided with a fly-wheel P, either of which may be used as a driving pulley. The hammer block H is attached to the hammer stem B, Figs. 1428 and 1429; it consists of a strong central core with a facing on each side, the whole securely bolted together and firmly held by trenails; the grain of the facing should run in a diagonal direction, and it is best for the two sides of the stem to have the grain

running at right angles to each other; the object of this arrangement is to expose a better biting surface to the rollers A than would be the case if the grain ran in the usual perpendicular direction. The hammer stem is made with a gradual taper on each side, and is formed with a sudden reduction of thickness at x. Motion being imparted to the friction rollers A, Fig. 1430, by means of a belt applied to one of the flywheels, the workman raises the lever E until the friction rollers nip the hammer stem, and the latter is then lifted by virtue of the friction which is produced between it and the rollers; by pressing down the lever E the hammer stem is released, and the hammer falls on to the anvil I, the force of the blow being in proportion to the height to which the hammer has been lifted. As the hammer stem is of a tapering form, it will only be raised by the friction rollers so long as they continue to approach each other, and so follow the reducing thickness of the stem; and consequently the hammer will only continue to be lifted as the operator continues to raise the lever E; when this is released the hammer will be held suspended by the action of the spring G. After the hammer has been raised to its full height the sudden thinning of the stem at x prevents its being raised any farther, and so avoids injury to the friction rollers. By these arrangements the hammer is capable of delivering blows with any required degree of rapidity or force; while at the same time it will be found almost as easy to control as an ordinary steam hammer.

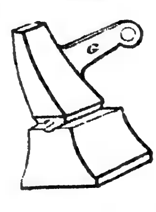
Stacy's revolving hammer, Fig. 1431, is arranged to deliver a series of elastic blows, in very rapid succession. When employed for shaping round bars, the faces of the hammers G and of the anvil I are shaped as in Fig. 1432; for reducing the thickness of plates, a hammer face as in Fig. 1433 is employed, where the rounded part of the face gives the blow, the flattened portion of the

1431.

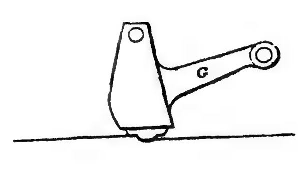


same acting as stops to regulate the amount of reduction in thickness which shall be given to the plate. The rotary shaft A is mounted in the arms B; the opposite ends of these arms being carried by the fixed axle C which is supported by the brackets D. Through the front end of the arm B there passes a rod E, the upper part of which is provided with a screw thread working in a fixed nut E′; and by means of this rod the axis A may be raised or lowered at pleasure, so as to accommodate the hammers G to the thickness of the work, and to regulate the force of the blow to be given. The curved arms F′ are cast with the boss F, and to their ends the hammers G are hinged; the joint pins of the hammers being equidistant from each other and from the axis of rotation. The arms F′, at about the centre of their length, are cast with swells having holes pierced through them to allow of the passage of the stop-pins H; which are screwed into the backs of the hammer heads G, and they are fitted with adjusting nuts at their free ends for determining the distance which the hammers shall fly out when impelled by centrifugal force. The hammer faces are slightly rounded at their forward part for the purpose of allowing the hammer to come fairly over its work before striking, and so causing it to deliver a swinging blow in the direction of a line radiating from the

1432.



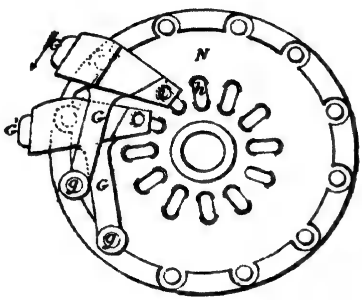
1433.



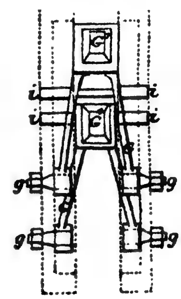
of the machine. The shaft A is driven by spur wheels L L′, and these receive motion and pulley MM′. The spur wheel L is keyed to the shaft A, and the wheel L′ and the shaft C. When the shaft A is slowly rotated in the direction

of the arrow the hammers are drawn over the work, simply pressing with the force due to their weight, controlled however by the stop-pins H; but as soon as the proper speed is attained, this dragging pressure is converted into a smart blow, the recoil from which will carry the hammer clear of the work. As the stops H revolve with the hammers, they limit the movement of the latter outwards, or away from the axis of rotation during their entire revolution; the blow is delivered while the hammer is at its outermost limit *a* against the stop. This hammer may be constructed with a greater number of striking faces G′, but in this case the hammers G are carried by two circular flanged plates N, Fig. 1434, and in place of the stops H, a series of radial slots *h* are provided equal to the number of the hammers, and in these slots slide the stop-pins *i*, the ends of the slots *h* being packed with some elastic substance in order to reduce shock. The hammers G are connected to the discs N by means of stud pins which pass through socket holes in them. The

1434.



1435.



stems of the hammers G are forked to allow the head of the adjacent hammer to pass through, as in Fig. 1435, and for the same purpose the sides of the hammer heads are recessed in order to allow of the free play of the hammers each within and independent of the other. Instead of employing the method of mounting and gearing, Fig. 1431, the hammer may be supported in bearings in the hanging brackets D, and driven direct from the belt by means of fast and loose pulleys on the shaft A; but in this case the anvil I must be capable of being raised and lowered to suit the different thicknesses of the work operated upon, and also for the purpose of regulating the force of the blow.

HEAT.

The principal theoretical considerations in the modern science of Thermodynamics have a direct bearing on many points in the construction of steam engines, in connection with the phenomena which periodically take place in an engine moving uniformly, regarded solely from a theoretical point of view, without any regard to mechanical details of construction. As an example, take the case of an expansive, high-pressure, condensing engine; it will be seen that the thermal phenomena naturally divide themselves into two classes.

A definite mass of water at a certain temperature, *t*, is delivered from the condenser into the boiler, and there converted into saturated vapour at a temperature, T. This change involves a calculable depression of the temperature of the products of combustion of the furnace.

The saturated vapour passes into the cylinder, impels the piston, and expands, after which it escapes to the condenser, where it is cooled down to the initial temperature, *t*, maintained constant by any suitable means. Also a certain quantity of heat is lost, being given up to raise or maintain constant the temperature of various surrounding bodies.

At the end of a double stroke the entire system is thus brought to identically the state in which it was at first, with, however, this important difference, that a certain amount of heat has been transferred from more to less highly heated bodies, and this will be the one essential condition required in order that any machine may be made capable of acting as a source of power.

As early as 1798 the heat generated in the boring of a cannon led Rumford to undertake a series of experiments with a view to ascertain the value of the mechanical equivalent of heat, that is, the amount of mechanical work, expressed in foot-pounds or any convenient measure, which will generate sufficient heat to raise the temperature of a certain quantity of water by a definite amount. Davy also made experiments on the same subject, but the first accurate results were those of Joule in 1843–49, whose experimental determinations confirmed those previously obtained by Mayer in Germany, mainly from theoretical considerations, and to these discoveries we owe a very large portion of our knowledge on this and other kindred subjects.

In Great Britain the mechanical equivalent is generally defined in terms of the foot, the pound, and Fahrenheit's scale of temperature, the unit of mechanical work being 1 lb. raised through a space of 1 foot. The heat-equivalent may therefore be defined to be that amount of work which, if exerted on 1 lb. of water at the ordinary temperature, would raise it one degree on Fahrenheit's scale; it has lately been found to be 772 foot-pounds. This is known as the First Law of Thermodynamics.

On the French or metrical system the metre, kilogramme, and centigrade scale are employed.

It will be seen that results expressed on the former system can be nearly converted to the latter by multiplying by the fraction 0·5486, and metric results can be expressed in English measure by multiplying by 1·8228. The form of the definition shows that the work done in raising any quantity of water, through a vertical height of 772 feet, would suffice to raise its temperature 1° Fahr.

For a detailed account of the methods which have been employed to determine the mechanical equivalent, the reader must be referred to the various treatises on heat, but Table I. shows the principal methods which have been employed and the results obtained.

TABLE I. RIGG.

Nature of the Phenomenon by means of which the Mechanical Equivalent was determined.	Authority by whom the Method was first suggested.	Name of Observer.	Result in English Measure.
General properties of air assumed to be a perfect gas	Mayer .. .. / Clausius	V. Regnault .. .. / Moll and Van Beck	768·6
Friction	Joule	Joule	772·69
		Favre	753
Action of the steam engine	Clausius	Hirn	752·8
Heat generated by induced currents ..	Joule	Joule	823·6
Heat generated by an electro-magnetic machine in action and at rest	Favre	Favre	807
Total heat generated in the circuit of a Daniell's battery	Bosscha	W. Weber .. .. / Joule	766
Heat generated in a metallic wire when traversed by a current	Clausius	Quintus-Icilius ..	729

The differences observed in the above results must be regarded as errors of experiment, for a certain amount of heat must of necessity have only one definite mechanical equivalent. This number is, as mentioned above, 772 foot-pounds in English measure, equivalent to 424·6 kilogram-metres on the French scale. As specially interesting in connection with applied mechanics, it may be well briefly to recapitulate the method adopted by Hirn in his experiments to determine the mechanical equivalent by the use of the steam engine itself.

Two sets of determinations were required, the thermal and the mechanical, and these may be considered separately.

With the engine moving at a uniform rate, the quantity of vapour consumed in a definite number of strokes was ascertained, as well as its temperature and pressure, care being taken to avoid both superheating and the presence of suspended drops of moisture; the total heat of vaporization at any given temperature being known, these data suffice for ascertaining the number of units of heat withdrawn from the furnace for the production of this quantity of vapour. To determine the heat given up to the condenser during the same period, it was only necessary to measure the quantity of cold water, at a known temperature, required to maintain a constant temperature in spite of the arrival of vapour in the condenser. The amount of heat lost by radiation and conduction was noted and deducted. To determine the mechanical effect, that is, the pressure at each instant in the cylinder, Hirn had recourse to Watt's indicator. The results obtained were very variable on account of the great number of sources of error, but the best is probably that given in Table I.

As bearing on these experiments, we may note a method designed by B. W. Farey, which consists essentially of a chest, into which the condenser water is conducted, provided with a float and a mercurial thermometer. A beam of light, after traversing a break in the mercurial column and a small hole in a piece of brass attached to the float, is projected on to a slowly rotating drum carrying sensitive paper, and lines are thus traced which indicate the amount and temperature of the water; from these data the quantity of heat can, of course, be at once calculated.

It is well known that the volume of a given mass of a substance varies with the pressure to which it is subjected, but to completely define the physical state in which it exists, the temperature must also be specified; for at higher temperatures greater pressures will be required to maintain a given volume. Hence, if the relation between volume and pressure be represented by points as in the indicator diagram, and all the points corresponding to a given temperature be joined to form a curve, this curve, called an isothermal line or line of equal temperature, will show the whole behaviour of the substance under the given conditions.

The simplest form of isothermal is that corresponding to a perfect gas, and although it is certain that nothing accurately obeys the laws of a perfect gas, yet it will be necessary first to consider such a one; and air, oxygen, nitrogen, or any of the gases which have not been liquefied by cold and pressure, may be taken to be perfect within the limits of experiment.

The laws which such a gas is found to obey are;—Boyle's or Mariotte's Law.—The volume of a given weight of a perfect gas varies inversely with the pressure, the temperature remaining constant. Charles' or Gay-Lussac's Law.—The volume of a perfect gas under constant pressure increases for each degree rise of temperature by the same fraction of itself, whatever be the nature of that gas. This fraction is found by experiment to be 0·003665, or $\frac{1}{273}$ for each degree Centigrade, and 0·002036, or $\frac{1}{491}$ for each degree Fahrenheit.

If rectangular axes O V, O P, Fig. 1436, be taken representing pressures and volumes on any arbitrary scales, the first of these laws supplies all the data requisite for drawing any given isothermal. For if V and P represent volume and pressure, Boyle's law asserts that

$$P \times V = \text{a constant.}$$

Now, it is shown in conic sections, that a rectangular hyperbola is the curve which satisfies the above condition, the axes being the asymptotes, or lines to which the curve is continually approaching, but never actually reaches.

From the second law above, it will be evident that when the isothermal corresponding to any

given temperature is known, those for all other temperatures can be at once calculated. For, if V_0, V, and V_1 are the volumes at the temperatures O, T, and T_1 degrees on Fahrenheit's scale, the pressure P remaining constant; we have by Charles' law

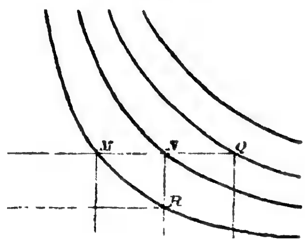
$$V = V_0\,(1 + 0{\cdot}002036\ T),\ \text{and}\ V_1 = V_0\,(1 + 0{\cdot}002036\ T_1).$$

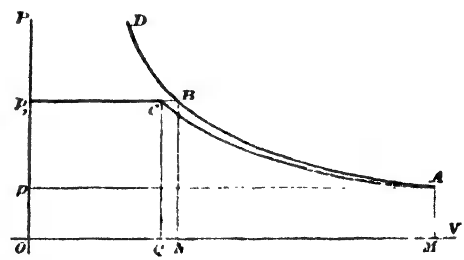
Therefore the curves corresponding to the temperatures O, T, and T_1 will be defined by the expressions

$$P\,V_0 = \text{a constant.}$$
$$P\,V_0\,(1 + 0{\cdot}002036\ T) = \text{a constant.}$$
$$P\,V_0\,(1 + 0{\cdot}002036\ T_1) = \text{a constant.}$$

The same axes being employed. The constant, of course, differs in each case, and is determined as soon as P and V_0 at any given point are ascertained.

1436.





Geometrically interpreted, these expressions show that the curves consist of a series of hyperbolæ parallel to each other, and having the same asymptotes; and further, if, while the pressure remains constant, the portions vv_1, v_1, v_2, be marked off, representing the increase of volume of the gas corresponding to 1° F. rise of temperature, at the constant pressure p, and the parallelograms, p O v M, p O v_1 N, p O v_2 Q, &c., be completed, the points M, N, Q, will be on isothermals corresponding to temperatures which differ by 1° F. from each other.

If two points M and R on any isothermal be considered, it will be seen that, by the condition referred to above as being involved in Boyle's law, the areas p M v O and p_1 R r_1 O are equal; now these are proportional to the intrinsic energy of the substance, and it is therefore clear that no work can be obtained from a perfect gas by simply changing its volume and pressure, the temperature being maintained constant, except by the application of a corresponding amount of heat.

Let us now turn to the case of those substances which do not fulfil the conditions of a perfect gas, such as carbonic acid gas, or, in a still less degree, steam. In such a gas, the volume decreases more rapidly than the pressure increases. Hence the expression P × V, decreases as we increase the pressure, and if at A, Fig. 1437, the isothermals of a perfect and imperfect gas coincide within the limits of observation, a second point B, corresponding to p_1, for the perfect gas will be obtained in the manner already explained; and C for the imperfect gas is given by constructing the rectangle p_1 O Q C equal to P × V, and as this expression decreases with an increase of pressure, the curve will be in all cases below that for a perfect gas at the same temperature. Of course steam in a very rarefied state approximates to a perfect gas, and the curves become practically identical, but on decreasing the volume they tend to diverge.

Let the case be taken of steam boiling at the atmospheric pressure, and let O p_1 represent that pressure; we shall thus obtain the isothermal corresponding to 212° F. Reduce the pressure so that the whole of the heated water may exist as steam, and then by means of a piston reduce the volume, maintaining the temperature constant.

At pressures well below one atmosphere, such as O p, the curve will be approximately a rectangular hyperbola, but at the atmospheric pressure its form will suddenly and entirely alter, becoming straight and parallel to the line of volumes, as represented by the line C p_1. It will be found impossible, retaining the temperature constant, to permanently raise the pressure until all the steam has been brought to a state of water, for any sudden increase of pressure will be at once neutralized by a reduction of steam to the liquid state, and the converse will be true in the case of a decrease of pressure; thus the isothermal will remain horizontal while the volume is decreased in the ratio of 165 to 1, when the condition will be represented by a point too near to p_1 to be distinguished on the scale of the figure. A great increase of pressure, as is well known, is required to appreciably alter the volume of water; hence when all the steam has been condensed, the isothermal becomes approximately vertical and rises from p_1 towards P. For higher temperatures than 212° F., the isothermals have a similar form, but as a greater pressure is required to produce condensation, the horizontal portion is proportionately shorter.

If the points, similar to C, at which condensation commences at the various temperatures, be joined, a steam line is obtained, such that all points outside it indicate a substance entirely gaseous. From what has just been said, this line must slope towards the vertical line of pressures, but a similar line, called the water line, passing through the points at which the horizontal portions of the isothermals become approximately vertical, that is, the points at which all the vapour is condensed, will slope from the vertical axis, but very slightly, since the volume of a given of water increases with a rise of temperature.

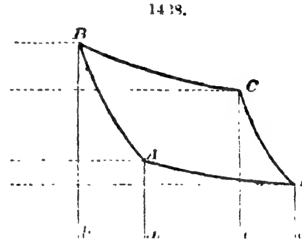
Dr. Andrews has made some very remarkable experiments on carbonic acid gas to ascertain whether the gas and liquid lines, corresponding to the steam and water lines in the case before us, ever meet, and he has proved that such is the case. He finds that if this gas be subjected, at a temperature of 88° F., to a pressure of 74 atmospheres, it is in a critical condition, and any slight change of pressure causes it to take entirely the liquid or the gaseous state. This is also the case at any higher temperature, with a corresponding increase of pressure; and as the temperature is still further increased, the form of the isothermal approximates to that for a perfect gas.

We have hitherto considered only the case of a fluid maintained at a constant temperature, but if it be so arranged that no heat either enters or leaves it, the nature of the curve is entirely altered. An experiment fulfilling such a condition is, of course, ideal, as no substance is impermeable to heat, but it is nevertheless possible, by the aid of complicated apparatus, to ascertain the form which the curve would take, and such curves, called Adiabatics, from two Greek words signifying "not passing through," are of very great importance in considering the properties of a substance in its relation to heat.

These explanations enable us to consider the remarkable work of Carnot, 1824. The great advances made in the science of thermodynamics since his time are due in great part to the introduction by him of the ideas of a cycle of operations and a reversible cycle. The first of these implies that in considering the working of a heat-engine, no assertion can be made with regard to the heat absorbed, unless the series of operations to which it is subjected be such that the steam and water are in precisely the same condition, as regards pressure, volume, and temperature, at the conclusion as they were at the commencement of the series.

In Fig. 1438 let A represent the condition, as regards pressure and volume, of a certain weight of any working substance, at the low temperature t, contained in a cylinder of some non-conducting substance which is closed by a piston without weight, and let us consider the cycle of operations represented by A B C D, in which A B, C D are adiabatics, and B C, A D are isothermals corresponding to the temperatures T and t respectively, of which T is the higher temperature.

1438.



In order to effect the operation represented by A B, the pressure must be increased from O 1 to O 2, by depressing the piston, no heat being allowed to escape, and this process being continued until the temperature is raised to T. Now it is shown in works on elementary mechanics, that the work done during the compression of a fluid is equal to the diminution of the volume of the fluid multiplied by the mean value of the pressure to which it is subjected. In the present case, the diminution of volume is represented by $a\,b$, and the mean pressure is the mean ordinate between B b and A a, and their product is evidently the area B $b\,a$ A. Hence the work *on* the substance is measured by the area B $b\,a$ A. and, with reference to the work obtainable from such an ideal engine, this is negative.

Now, allow the volume to increase gradually, at the same time communicating sufficient heat to maintain the temperature constant. The process will be represented by the isothermal B C, and the volume will increase from that represented by b to that represented by c. As, however, the volume is increasing, the working substance is doing work on external bodies, and this, represented by B $b\,c$ C, is therefore positive. This, it must be noted, is the only operation during which heat is absorbed by the substance.

In the third operation, allow the body to expand without losing heat, and thus to traverse the adiabatic C D, and let this expansion continue until it has occasioned a fall in the temperature of the working substance from T to t. Positive work represented by C $c\,d$ D is thus obtained.

In the fourth, and final operation, the piston is depressed, the temperature being maintained constant by withdrawing heat, until the initial volume is attained. The work during this process is negative, and is measured by the area D $d\,a$ A.

The cycle is now complete, and, since the substance has been brought to its exact initial condition, we are at liberty to reason upon the relation between the work acquired and the heat spent in acquiring it. The figure shows at once that the positive work exceeds the negative, by an amount represented by the figure A B C D, traced out during the cycle. The second is the only operation during which heat is communicated to the body, and during the fourth alone is heat withdrawn from it. Hence the work represented by A B C D is obtained by the putting out of existence of an amount of heat H − h, supposing H and h to be the first and second of these quantities.

It will be at once seen that the above cycle of operations is reversible, that is, we may, commencing at the same condition of temperature, volume, and pressure, as represented by the point A, cause the working substance to assume the conditions D C B A in succession, by (1) expanding at the lower temperature t, during which it will absorb an amount of heat h; (2) compressing without losing heat to C, when it will have the temperature T; then (3) compressing at this temperature to the volume O b, during which operation an amount of heat H will be given out; and finally (4) allowing it to expand without receiving heat to the volume O a. This reverse action shows that it is possible to transfer heat from a cold body to a hot body, but an examination of the figure makes evident the fact that this transference requires the expenditure of a quantity of work measured by the area A B C D.

It is important to bear in mind that each of the above reversals is a legitimate one. Thus, it is just as easy, physically, to cause the condition of a body to pass from C to B along the line B C, as from B to C, but if, instead of compression and expansion, conduction had been resorted to in order to transfer heat from the hot body to the colder body, no legitimate reversal of this could be effected, for heat will not pass from a cold to a hot body by conduction.

Carnot laid down the principle with regard to the purely theoretical consideration of a reversible engine, that is, reversible in the thermodynamic sense, and not in the sense ordinarily employed by engineers. If a reversible engine working between the temperatures T and t, and receiving an amount H of heat at the higher temperature, produces a quantity of mechanical work W, then no other engine of any construction can produce a greater quantity of work under similar conditions. The fraction $\frac{W}{H}$ is called the efficiency of an engine, both W and H being measured in foot-pounds; a reversible engine, therefore, has a maximum efficiency, and this fact is capable of very simple proof. For if an engine M be assumed to exist with a greater efficiency and set to work the reversible engine N in the reverse way, it will, through its greater efficiency, be able to raise by the engine N a quantity of heat from the cold to the hot body in excess of that required to work it; energy will thus be stored up by the combined engines and perpetual motion become possible, the absurdity of which may be taken to be axiomatic.

The results arrived at by following Carnot's system of reasoning lead to the second law of thermodynamics, which is thus stated by Thomson;—"It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects." Thomson was led by it to the discovery that the absolute zero of temperature, or the point at which no heat whatever resides in a substance, is at $-461°$ F., and this fact gives an easy means of defining the efficiency of a perfect engine. This efficiency may be shown to be equal to $\frac{S-T}{S}$, where S and T are the absolute temperatures of the source of heat and condenser respectively, obtained by adding the above number to the temperature expressed on the Fahrenheit scale. Thus, suppose an ordinary high-pressure engine to be working at a pressure of 53 lb., the temperature of the boiler will be about 300° F., and the condenser will probably have a temperature of about 100° F. Now, suppose this engine to be perfect, its efficiency will be given by the fraction

$$\frac{(300+461)-(100+461)}{300+461}, \text{ or } 0\cdot262.$$

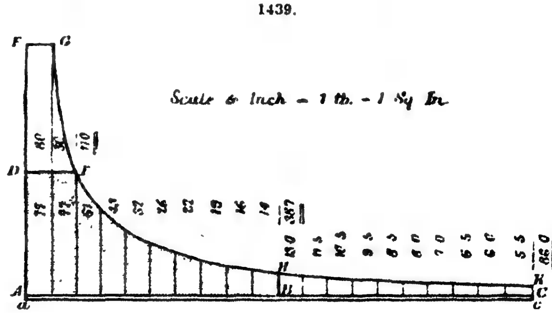
That is, nearly three-fourths of the heat supplied to an engine working under the ordinary conditions, but supposed to be perfect, and therefore reversible, would be unavailable for conversion into work.

It will thus be seen that the efficiency of an engine depends solely on the range of temperature within which it works, and the determining of this is of great importance in the construction and management of steam engines; for its extension in one direction involves additional strength of boiler; and in the other, greater condensing power.

The amount of expansion that can be made practically useful has been a fruitful subject of discussion and controversy, and it has been shown by practical experience, rather than by theoretical deduction, that it is not advantageous to carry the rate of expansion beyond limits which themselves have not up to the present time been clearly defined. But apart from the theoretical aspect of this question, which is often obscured by uncertainties connected with the action of heat, there is a very practical aspect from which the subject may be approached; and it will be the object of the succeeding remarks to make this aspect clear.

The indicator diagram, Fig. 1439, shows the advantages gained by doubling the pressure, or by doubling the amount of expansion in a particular case; the cost of such a change can also be considered, and thus the points defined beyond which expansion would not be worth having, in consequence of the cost incurred in obtaining it.

1439.



Let A B represent the stroke of a piston, say 30 in., to a scale of 1 in. to 1 ft., and A D a pressure of 77 lb. a square inch, there being 3 lb. lost from the original 80 lb. in overcoming back pressure A a in the condenser, and steam is cut off at E, or one-fifth of the stroke. Under these circumstances, a measurement in the ordinary manner will indicate an average pressure of 38·7 lb. a square inch to impel the piston.

Let the steam pressure be now raised to 160 lb. a square inch, and the diagram will assume the form A B H G F, the area being increased by D E F G, which represents the amount gained by the additional pressure, cut off being at one-tenth of the stroke. This additional area gives 55 lb. pressure through one-fifth of the stroke, or 11 lb. if distributed throughout the entire stroke.

Thus, to gain 11 lb. above 38·7, or 28 per cent., it has been necessary to double the steam pressure, and add very considerably to the strength of all parts composing the engine.

Now, suppose the pressure to be 77 lb. a square inch, and instead of expanding this steam five times it is expanded ten times, which is equivalent to doubling the stroke from 30 in. to 5 ft., as represented by the line A C. In this case the pressure gained amounts to 8·6 lb., measured by the space B C K H, for the latter half of the stroke, or 4·3 lb. average increase throughout.

By such a change we double the length of the stroke for the purpose of gaining 4·3 lb., namely, a gain of 11 per cent. beyond the original total of 38·7, when steam of 80 lb. a square inch is cut

off at one-fifth of the stroke, but when steam of 160 lb. is employed and cut off at one-twentieth of the stroke, the gain is only 8·7 per cent.

With higher pressures or rates of expansion the differences become greater, until a time is manifestly reached when the increase of strength or size of the engine becomes so great as to put a stop to all further adventure, and we arrive at the conclusion that it is not worth while to expand beyond certain limits; only from a constructor's point of view; and therefore many engineers prefer to employ comparatively low rates of expansion and even wire-drawing the steam, rather than risk the danger of exceedingly high rates with its comparatively small advantage.

The compound system of constructing engines is found extremely useful where a high rate of expansion accompanies a low speed of rotation; but there does not appear to be any reason deducible from theory or from practice, by which it can be proved that low speed is essential.

Laws which relate to the development of heat, and their effects upon various bodies under its many influences, affect greatly the operations of the engineer; they have been discovered mainly by experiment. Mathematical expressions are employed to indicate the results arrived at by these experiments; and as solutions of the main problems connected with the expansion of gases and those connected with mechanics have been derived from accurate theoretical and mathematical investigations, they may be relied on to exhibit results with great accuracy. The principal agent in which heat is employed by engineers is the steam engine, and it is therefore important to study the action of heat on the boiler, inasmuch as through it all the processes preliminary to the actual use of steam are effected, and a sound knowledge of the proper forms of construction and principles of management of this apparatus is, therefore, of as much importance as a knowledge of the laws of expansion, and of the mechanical motion by which the heat of steam is utilized. Apart from this, phenomena connected with heat are so common and universal, so intimately related to the various branches of technology, that it is of all the physical agents one of the most important and varied in its influence.

Heat has been defined as being a mode of motion, a definition which suggests the idea that it is derived from molecular movements of the atoms of substances. But such a definition, although valuable, requires qualification, since motion in the abstract does not take into account force or energy. The existence of power is, however, not difficult to conceive in connection with motion, if this be that of a mass or ponderable body. This *vis viva*, or living force, is an expression employed to designate the capacity for performing work which results from the motion of bodies, and is the effect of the velocity and mass combined, the measure of this capacity being the mass multiplied by half the square of the velocity. This is one of the most universally accepted principles of mechanics, and also one of the most commonly used, since it performs a principal part in nearly all the devices for the utilization of the various natural forces. The condition of the body, the particles of which are agitated by this peculiar heat-motion, is thus a condition of energy. It is a certain amount of actual energy due to its mass and the resultant motion of its molecules. This may be expended just as the energy of the flywheel is expended in overcoming resistance and performing work, or it may be increased by having its velocity of heat-motion increased, just as the energy of the flywheel is increased by energy stored up by increased velocity. In the first case, the work of this force is converted into the energy of the flywheel; in the second, the *vis viva* disappears as the motion is diminished, and is transformed into external work. The living force which constitutes the energy or power of heat, although not accompanied by a visible defined motion of the whole mass of a body in one direction, is nevertheless precisely similar, and acts according to the same law. The precise condition of the heat-motion of the molecules of substances has not been determined, and the ultimate arrangement of the molecules, in the formation of bodies, is still a subject of conjecture; still, however, it is a generally accepted theory, that the molecules of substances have a vibratory or oscillating motion of a peculiar character, which we can call heat-motion.

The space traversed by the atoms at every vibration is so minute as to be imperceptible, but it must not be forgotten that the vibrations in an ordinary unit of time are very great. Heat-motion is a property of every substance which exists, and without it in nature animal life would cease to be, while the elements would exhibit an entire change. Thus heat may be regarded as a property of matter, since all things, whether solid, liquid, or gaseous, are, so far as we know, animated by this peculiar motion. Variation in heat of a body, according to the dynamic theory, merely indicates a change in the velocity at which the molecules vibrate; and, as they have weight or mass, a change of heat involves the development or decrease of the living force.

It is convenient to consider the manifestations of heat in three ways; by treating of this action in a body as a source of power in doing work apart from the body in which it exists, and in altering the relations of the molecules and producing variations of volume in the body itself; and, from the opposite point of view, the producing of heat, with attendant variations in density and volume, by the application of work on the outside. We may also consider the variations of form and other properties to which bodies are subject when submitted to variations of heat, and again, the conveyance of heat from one body to another, this latter phenomenon involving the introduction of an element in the material world, the existence of which can only be proved by scientific reasoning and analogy. While the molecules of substances are aggregated closely and have constant motion, there is presumed to be a gaseous or ethereal substance pervading space, the particles of which are so small, as compared with ordinary material atoms, that this ether permeates the spaces between the atoms of substances, and is capable of being set in motion by their action, whilst conversely, motion, communicated to the ethereal medium at a point external to a body, and transmitted as waves, may, through the action of these waves with the molecules of a body, impart motion to them; radiation of heat is then but a wave-motion communicated to the ethereal medium by the action of the molecules of bodies. Heated bodies lose heat-motion and living force in sending off waves in this medium, and other bodies in the path of these waves will have the motion of their molecules increased in velocity and will become heated, the particles of the medium having weight or mass possess energy when in motion, and impart this energy to the mate-

rial atoms. Thus arise the phenomena of radiant heat and light, which, when observed in reference to the wave-motion alone, present those interesting effects which rise from different lengths and velocities of the waves, interference, pulverization, refraction, and reflection, giving rise to different colours, as well as heating effects from the same motive source.

Every body, by which is to be understood a definite quantity by weight or volume of a given substance, is supposed to be composed of heavy atoms, each of which is in constant motion, though the velocity of oscillation of all the molecules may not be identical. An average velocity is, however, the result, and the living force of the whole body, due to the heat-motion of all the molecules, may be expressed by the well-known law $\frac{M V^2}{2}$, and if V_1 represent any other velocity the actual energy corresponding to this velocity will be $\frac{M V_1^2}{2}$, and the difference $M\left(\frac{V^2 - V_1^2}{2}\right)$ will represent the expenditure of energy or the work of inertia due to the change. If there is a loss of heat for a loss of velocity, energy will be expended, and if the reverse it will be stored.

As a flywheel possesses power, derived from its mass and rapid motion, to drive machinery, so all substances possess energy, derived from the rapid oscillation of the individual molecules, to perform work when these oscillations are diminished; the rapid oscillations of the molecules of steam or gas constitute the source of power in heat-engines; these particles, enclosed by a cylinder, strike the piston and give it motion; the effect on the heat-motion of the molecules being to diminish the living force of the whole mass of steam enclosed, by a quantity which is equal to the work performed by the piston. This force of inertia it is which we utilize under the name of heat, and which has become a universal aid. By utilizing the process of combustion in a steam boiler, heat-motion is rapidly developed in the fuel and gaseous products of combustion, and transferred to the particles of water, from which it is transferred to the steam engine where the heat-motion is again distributed; the inertia developed by this change being the force which performs the work of the machine. When work is thus effected there is an exact balance between the cause and effect. It is well known in mechanics that the expression $M\left(\frac{V^2 - V_1^2}{2}\right) = P \times h$, that is, the work executed by the inertia of the mass M, when its velocity is changed from V to V_1, is equal to the work estimated by multiplying a force P by a distance h. To find the value of $P \times h$, it is only necessary to give numerical values to M, V, and V_1. M is equal to $\frac{W}{g}$, that is the weight divided by the expression for the force of gravity; V and V_1 are usually determined by experiment, and are expressed in feet a second. When this expression represents the work performed by the inertia for a given change of heat-motion, it becomes difficult to give numerical values to the quantities. The mass may be found as before, being the weight of the body divided by the force of gravity, but the velocities V and V_1 belong to motions which we cannot perceive. $P \times h$ may, however, be expressed in the same numerical terms as before, a pressure or weight multiplied by the distance through which it acts; it is evident that where the whole effect of a change of heat is the performance of a certain work $P \times h$, if the external work can be measured, the numerical value of the first member may be determined.

Joule's experiments were made with this object. He had an apparatus consisting of a small cylindrical vessel filled with water, in which were blades made to revolve by the application of power, furnished by a weight to a cord passed over a fixed pulley. The water in the vessel was prevented from rotating in a vortex with the blades, so that the only effect of the motion of the blades was to produce friction among the molecules of water; and the work exerted to drive the blades, namely, a weight falling through a height, was measured. The question then to be settled is how to estimate the change of heat which a given amount of work produces; there must necessarily be some unit for such a measurement, and since the velocity of the molecules cannot be observed recourse is had to an arbitrary unit of heat. If we were to represent the quantity of heat lost or gained in one unit of time by one, we could also show any other quantity of heat, if we multiply this by a number of seconds, and the expression $M\left(\frac{V_2^2 - V_1^2}{2}\right)$ would be represented in terms of this unit, and it would only remain to determine by experiment, how many units of work correspond to one unit of heat, or the value of $P \times h$ for one unit of heat. We have not, however, always the same source of heating or cooling, for heat-motion is developed or destroyed by a variety of physical agencies, such as chemical composition, decomposition, electricity, radiation, and conduction. Some other arbitrary unit must therefore be found, and advantage taken of the property which all substances possess of changing form when heated or cooled, independently of the source of such action. We know from observation and experience that upon heating, most substances expand in volume, and contract in cooling; and we also know that these changes are independent of the source by which they are caused. This law is so invariable that the amount of expansion of a body may be taken to indicate changes of heat. Upon this idea the common thermometer is constructed, and when it is applied to a body it indicates the velocity of heat-motion of the molecules which is more or less rapid, according to the expansion of the fluid of the thermometer as indicated by the scale. We have then what are known as degrees of heat and degrees of temperature, this latter indicating a condition of the body merely, and changing in a manner proportionate to the change of heat, and because the thermometer is brought into a condition of heat, in equilibrium to that of the body to which it is applied, by mere proximity, it may be said to indicate the sensible heat of the body, or its ability to communicate heat. If we take a pound of water, and cause a change of heat, indicated by a change of temperature of one degree of the thermometer, the mass or weight is known, and we have a measurable quantity; the volume of mercury, or other substance employed, is the thermometer, which changes with the changes of heat, and as $\frac{M V^2}{2}$ changes. We can then assume a change of heat

corresponding to 1 lb. of water raised in temperature one degree to be one unit of heat. It was found by Joule that one unit of heat is equivalent to 772 foot-pounds of work, water being taken at a temperature of 39°·1 F. when it is of maximum density, and this has been frequently corroborated, so that 772 foot-pounds is now known as the dynamic equivalent of a unit of heat in English measures. In French measures the unit of heat is called a calorie, and is the quantity of heat which corresponds to a change of heat indicated by one degree of the Centigrade thermometer in one kilogramme of water, equivalent to 423·55 kilogrammetres raised one metre. In applying mathematical investigations to the subject of heat, 772 foot-pounds is called the quantity of heat represented by unity. If W represents any quantity of work in foot-pounds, $\frac{W}{772}$ will represent the equivalent quantity of heat represented in heat units, or q expressed in heat units multiplied by 772 will give the number of foot-pounds equal to a given quantity of heat; the heat units or specific heats of bodies vary, and, as it is convenient to have a standard unit of heat, that of water is taken, and the specific heats of other substances are expressed relatively to it. It will be understood in regard to specific heat that all known substances, except hydrogen, require less heat for a change of temperature of one pound of the substance one degree, than that which is required for water; this is an accidental property, but the result is that in a table of specific heats the numbers which represent them are, with the exception of that for hydrogen, less than unity. A quantity of heat represented by q, that is a change of heat equivalent to q expressed in heat units, may be represented by $q = W \times c \times F$, W being the weight of the body, c the specific heat, and F the number of degrees of the change of temperature.

TABLE II.—SPECIFIC HEATS.

Copper	0·0951	Alumina	0·1970
Gold	0·0324	Stones, bricks, about	0·2200
Iron	0·1138	Water	1·0000
Lead	0·0314	Lead, melted	0·0402
Platinum	0·0324	Sulphur „	0·2340
Silver	0·0570	Bismuth „	0·0363
Tin	0·0562	Tin „	0·0637
Zinc	0·0955	Mercury	0·0332
Brass	0·0939	Alcohol	0·6150
Glass	0·1977	Fusel oil	0·5640
Ice	0·5040	Benzine	0·4500
Sulphur	0·2020	Ether	0·5034
Charcoal	0·2410		

	At Constant Pressure.	At Constant Volume.
Air	0·238	0·169
Oxygen	0·218	0·156
Hydrogen	3·405	2·410
Steam gas	0·480	0·346
Carbonic acid	0·217	..
Nitrogen	0·244	..
Olefiant gas	0·404	0·173
Carbonic oxide	0·245	0·237
Ammonia	0·508	0·299

Table II. indicates the mean specific heats of the various substances detailed; they show average values taken at temperatures which are usually observed in technical application; the actual specific heats of all substances increase slowly as the body expands, or as the temperature rises, and when accurate results are necessary special tables may be consulted, which give these quantities with greater precision at special temperatures. As an example of the use of these tables, we will suppose it is required to ascertain what rise of temperature will result from the transfer of 500 units of heat by any process whatever, such as radiation or friction, to 200 lb. of iron taken at any ordinary temperature; here

$$F = \frac{q}{W \times c} = \frac{500}{22 \cdot 76} = 21° \cdot 97.$$

The specific heats of gases are given for constant pressure and constant volume. It is well known that a gaseous substance, to be treated as a quantity or body having volume, must be confined by some envelope, or within an enclosure through the sides of which the gas cannot escape. Such an enclosure may have an invariable volume, that is, its sides may not yield to any pressure from the interior, or it may have a variable volume, as when air is enclosed in an elastic envelope, or within a cylinder having one end movable. The effect of transferring an additional quantity of heat to a given weight of gas is to cause it to expand in volume if the envelope will admit of expansion.

If the envelope expands sufficiently to adjust the new volume to the external pressure, this external pressure being constant, the specific heats to be employed in determining quantities of heat are those given under the head constant pressure.

If the volume remain invariable, the specific heats to be used are those under the head constant volume.

A definite quantity of any given substance requires three conditions for its existence in a separate and distinct form; they are volume, pressure, and temperature; that is, the actual space occupied by the substance without regard to the form of that space; the resistance of the external envelope of the body to its expansion; and the condition of heat-motion of its molecules. Heat

transferred to a solid not only causes an increase of molecular vibration, which is shown by an increase of temperature, but an expansion which consists in the separation of the particles from each other, and its expansion involves the overcoming of the external pressure of the enveloping medium, the same effects being exhibited in fluids by a transfer of heat. With perfect gases, however, the molecules being already entirely separated, the effect of the transfer of heat is only to increase the vibration of the molecules, to increase the sensible heat, and to overcome the external pressure, as before stated; the entire reverse is the case when heat is abstracted.

Let A represent the molecular movement, B the amount of expansion, and C the change of volume, we have for q the total effect of the heat transferred.

$$q = \frac{A + B + C}{772}.$$

In solids and liquids, the expansion being small in comparison with the original volume, C will be very small, and may ordinarily be left out of consideration; in perfect gases, the forces of attraction of the molecules having been entirely overcome, B will disappear, $q = \frac{A + C}{772}$.

This is the most important expression of q, because the employment of heat as a source of power is usually through the agency of gases, and the expression shows that the effect of a change of heat merely varies the molecular vibration of the gas, involving living force and the overcoming of external pressures; this has been shown by Thomson in the case of bodies which are known, by observation, to contract when heated at certain temperatures, or to expand when cooled, as water and some alloys; C will be reversed at these points, and the expression will furnish an explanation of the peculiar phenomenon, that under these circumstances the increase of external pressure will lower the temperature of fusion or congelation. These general laws are, however, subjected to a few remarkable exceptions; the enunciation of the law that bodies, when heated and then cooled to the original temperature, regain their original volume, requires a further condition in the case of most solids, the cooling must take place slowly and gradually, otherwise the original volume may not be regained, and peculiar effects, such as brittleness and hardness, are often produced, which are difficult of explanation; the process of annealing, or slow cooling, is therefore essential when certain conditions in these respects are desired.

The rate of expansion of a body, is the increase of volume which takes place for equal increments of temperature, the volumes being referred, in each case, to the volume of the same body at a standard temperature. When the body exists in the form of a rod or bar, the length of which is to be determined under different degrees of heat, the increase of length is called the linear expansion. This is not a measure of the total increase of volume, but it is practically convenient to know the linear expansion as well as the cubical expansion.

A table of linear expansion gives the numbers by which it is necessary to multiply the lengths of rods or bars at 32° F. in order to find the lengths of the same rods or bars at 212° F. That is, the number show the increase of length of rods of the same substance for 180° F. from 32° F. The proportional expansion for 1° F. may be found by dividing each number by 180.

The cubical expansion, or coefficient of expansion of volume, for any substance may be obtained by multiplying the linear expansion by 3 as in Table VI. The coefficients of linear and cubical expansion thus found are average values for degrees of heat between 32° and 212°, but these coefficients become slightly greater at higher temperatures; the general rule being that the coefficient of expansion increases the more rapidly, as the temperature approaches that which corresponds to the melting or fusing point.

The continuous transfer of heat to a solid, causing a continuous rise of temperature and expansion of volume, produces ultimately a change of aggregation or change of state to the liquid form, called the fusion, melting, or liquefaction of the substance.

The law is general for substances which do not change their composition in changing their state. For substances which do not change their composition, the following phenomena occur; each substance begins to melt at a certain temperature, which is constant for the same substance if the pressure be constant. The temperature of the solid remains at this constant point from the time when fusion commences till it is complete. If a substance expands in congelation, its melting point is lowered by pressure; but if a substance contracts in congealing, its melting point, or point of congelation, is raised by pressure.

Table III. of melting points in F. degrees is taken from Rankine's 'Rules and Tables';—

Table III.—Melting Points.

Mercury	38° F.	Silver	1280° F.
Ice	32° „	Brass	1869° „
Rose's fusible metal, 1 part lead, 1 tin, 2 parts bismuth	210°	Copper	2548° „
Sulphur	228°	Gold	2590° „
Tin	426°	Cast iron	3479° „
Bismuth	493°	Wrought iron	higher, but uncertain.
Lead	630°	Phosphorus	111° F.
Zinc	700°	Wax	147° „

The temperature at which melting occurs is, for most substances, fixed; this temperature indicating the limiting condition above which the substance exists as a liquid, and below which it must exist as a solid. The laws which have been enunciated are subject to certain qualifications, such as slow process of cooling, and variations of external pressure, which may lower the temperature of solidification, but under the same conditions they are invariable. The continuous application

of heat to a solid at its melting point does not raise its temperature, as long as any portion remains solid; and, commonly, the abstraction of heat from a liquid at its point of solidification does not lower its temperature, as long as any portion remains liquid. The change of state is also usually accompanied by a sudden change of volume.

Some substances, however, pass from the solid to the liquid state without showing a definite melting point, becoming plastic between these states. Glass and iron are examples, and instead of a definite melting point, a certain interval of temperature is required for the change.

When bodies pass from the solid to the liquid state, the increased rate of expansion is generally followed by a further expansion, so that the substance, after fusion, occupies a greater bulk at the same temperature than before fusion.

Phosphorus expands at the moment of fusion about 3·4 per cent., sulphur 5 per cent., wax very slightly, stearine about 5 per cent. Rose's fusible metal exhibits remarkable properties in this respect. When heated from 32° F. to about 108°, it expands in the ratio of 1 to 1·0027; as the temperature is further increased, it contracts, its volume at 190° F. being the same as at 32°. In melting it expands again, so that at 208° its volume is 1·01 of its volume at 32°. This alloy, therefore, contracts from 108° to its melting point. Water, as is well known, expands at the moment of freezing, or contracts in melting about 10 per cent.; one volume of water at 32° F. gives 1·102 volumes of ice, and one volume of ice ·908 volume of water at the same temperature. Bismuth, cast iron, and antimony expand like water in passing from the liquid to the solid state.

The increase of the specific heat of a solid, as it approaches its melting point, appears to be connected with the increase of the coefficient of expansion, which also increases simultaneously. At the melting point the whole of the heat applied to a body is, apparently, required to overcome those molecular attractions, which keep the molecules in the state of proximity belonging to the solid condition. The work of the heat applied is thus absorbed or expended without producing increased molecular vibrations.

Heat which would have become sensible heat in the pure solid or liquid, disappears or is transformed into the work of overcoming these molecular attractions, and is said to become latent. The latent heats of fusion of a few substances estimated in units of heat, have been determined experimentally by various observers, and some of these are exhibited in Table IV.

TABLE IV.—LATENT HEATS OF FUSION OF DIFFERENT SUBSTANCES.

Mercury	5·086	British units of heat.
Phosphorus	9·018	,, ,,
Lead	9·740	,, ,,
Sulphur	16·954	,, ,,
Bismuth	22·726	,, ,,
Tin	25·702	,, ,,
Silver	38·057	,, ,,
Zinc	50·682	,, ,,
Ice	140·000	,, ,,

The coefficient of expansion of liquids with increase of temperature is greater than that of solids, and, as in the case of solids, the coefficient increases with the temperature.

The coefficient of expansion of mercury, that is, the increase of volume for 1° C. in terms of the volume at 0°, or the melting point of ice, increases from 0·000179 at 0° C. to ·000197 at 350° C.

The following Table V. gives the increase in volume of water from the experiments of Kopp.

TABLE V.—EXPANSION OF WATER FROM 0° CENTIGRADE TO 100°.

4°	1·000000	50°	1·011890
10°	1·000247	60°	1·016715
15°	1·000818	70°	1·022371
20°	1·001690	80°	1·028707
30°	1·004187	90°	1·035524
40°	1·007654	100°	1·043114

When cooled below 39°·1 F., water expands by a corresponding and nearly identical law for a limited number of degrees.

In regard to very volatile liquids, like carbonic acid, which retains its liquid state at ordinary temperatures only under very great pressure, the coefficient of expansion is supposed to be large relatively. Each liquid has a coefficient of expansion different from that of other liquids. To this fact may be added the general law, that the coefficient of expansion of the same liquid, varies with the temperature according to a special law for each fluid.

It may be observed, from the tables of coefficients of expansion for solids and liquids, that the total change of volume from the lowest to the highest temperature, consistent with the solid or liquid condition of any substance, is very small compared with the actual volume of the body which undergoes such a change, and hence the influence of the external pressure upon the bounding surfaces is very slight during the change. The work performed by heat in expanding liquids and solids, may be regarded as entirely expended in producing change of temperature and change of aggregation, the external work in all ordinary cases, especially when the solid or liquid is exposed only to atmospheric pressure, being so small that it may be disregarded.

In the case of bodies in the gaseous condition, however, this is different. Gaseous bodies cannot exist in a fixed or determinate volume, ordinarily, unless they are enclosed within bounding surfaces or envelopes.

For a definite volume of a gas thus confined, there are thus but two conditions involved in its existence, the temperature, and the pressure which it exerts against the bounding surfaces of the

envelope. If such an envelope be perfectly elastic and heat be transferred to the gas, the external pressure, such as the pressure of the atmosphere, remaining constant, the effect will be an expansion of volume. This expansion will be much greater than the expansion of liquids and solids for the same increase of heat.

The coefficient of expansion or increase of volume under such circumstances, for an increase of temperature of 1° F., has been determined, through the well-known experiments of Regnault and others, to be 0·002035 or $\frac{1}{491\cdot4}$ of the volume of the gas at 32° F., and for 1° C., 0·00365 or $\frac{1}{273}$ of the volume of the gas at 0° C.

If we now compare the cubical dilation of solids, liquids, and gases in a general way, as in Table VI., we may take for such comparison the increase of volume from 0° to 100° C., or 32° and 212° F.

TABLE VI.—EXPANSION FOR 100° C.

Gases	0·365	Wrought iron and steel	0·0036
Liquids.		Lead	0·0057
Pure water	0·04775	Tin	0·0066
Sea-water	0·05	Zinc	0·0058
Spirits of wine	0·1112	Brick, common	0·0106
Mercury	0·0182	Firebrick	0·0015
Oil, linseed and olive	0·08	Cement	0·0042
Solids.		Glass	0·0027
Brass	0·0065	Slate	0·0031
Bronze	0·0054	*Average Values.*	
Copper	0·0055	Solids	0·005
Cast iron	0·0033	Liquids	0·060

The expansion of gases, 0·365, is strictly true only for the perfect gases, namely, gases which have not been liquefied.

In the above comparison of the changes of volume of solids, liquids, and gases under equal changes of heat, the coefficients for solids and liquids are only mean values between 0° and 100° C.

And, moreover, as before remarked, each solid or liquid substance has its own coefficient, which increases slightly as the temperature rises. In regard to gases, however, a more simple law holds true. The coefficient ·00365 for each degree C., or ·0020276 for F., is the same for all perfect gases and for all pressures upon the external envelope, provided only that the pressure be constant during the change of volume, or during the transfer of heat. Thus one volume of a perfect gas at 0° C., or 32° F., will become 1 + 0·00365 or $1\frac{1}{273}$ volume at 1° C., or 1 + 0·002035 or $1\frac{1}{491\cdot4}$ volume at 32° + 1° F. A slight difference in the coefficients was found by Regnault for the different gases, and also a slight difference at different external pressures, but for purposes of ordinary calculation the coefficients of all perfect gases may be regarded as the same.

We may conceive, however, that when heat is transferred to a gas enclosed within an envelope, for instance within a cylinder which is closed at one end by a movable piston, the volume and the external pressure may change simultaneously, and thus the three quantities which determine the condition of the gas, namely, the volume V, the pressure P, and the temperature t, may all be variable quantities.

The relation between these quantities, under such conditions, has been found, and is represented by what is well known as the law of Mariotte and Gay-Lussac. The following equation is the mathematical enunciation of this law;—

$$P\,V = R\,(a + t),$$

in which P is the external pressure upon unit of surface, V the volume of unit of weight, R a constant which depends on the specific gravity or density of the gas, the weight of this unit of volume; t the temperature, and a the number 273, Centigrade degrees being employed, and 459·4 if Fahrenheit degrees be employed.

The quantity P, defined as the external pressure upon a unit of surface, is evidently also the outward pressure of the gas. In the illustration, in which the gas is supposed to be confined in a cylinder with a movable piston, it is apparent that when there is a state of equilibrium, the external and internal pressures must be equal. Hence the pressure P is also called with propriety the elastic force of the gas, which is always exerted in an outward direction.

Mariotte's and Gay-Lussac's laws combined are expressed by the following formulas;—

$$\frac{P\,V}{459\cdot4 + t} = \frac{P_0\,V_0}{459\cdot4 + t_0}, \text{ for Fahrenheit degrees.}$$

In this expression P represents the pressure in pounds upon one square foot, and V the volume in cubic feet occupied by one pound of the gas at any temperature t; P_0, V_0, and t_0 represent respectively the pressure, volume, and temperature of the gas at 0° Centigrade, or 32° Fahrenheit.

The specific heat of a substance has already been referred to, as the quantity of heat, in units of heat, necessary to cause a change of 1° in the temperature of one unit of weight of the substance, at some standard temperature and pressure.

A standard temperature and pressure are necessary, because the specific heats of all substances, except perfect gases, vary slightly with the external pressure, and with the temperature. The unit of heat in English measures, to which other special units or specific heats are referred, has been defined to be the quantity of heat necessary to cause a change of 1° in 1 lb. of pure water at the

temperature of 39°·1 F., and the specific heats of the tables are expressed in fractions of the unit of heat.

The expression

$$Q = \frac{1}{772}(A + B + C),$$

which illustrates the effects of a change of heat q in any substance, solid, liquid, or gaseous, shows that a quantity of heat added to a given quantity of any substance causes these effects, as has been already stated, namely, increase of molecular vibration, or increase of sensible heat represented by A; change of position of the particles, overcoming forces of attraction, B; and overcoming external pressure C, arising from expansion or increase of volume.

From this it appears that the change of sensible heat represented by A does not include all of the heat involved in the change, and the thermometer will give only an apparent specific heat, the real specific heat being the whole heat, part of which has been expended in producing the effects B and C, representing internal and external work, and which has disappeared as heat.

If the substance can be confined to a constant volume, it is evident that these terms will vanish, and the apparent will be also the real specific heat.

In solids and liquids the amount of expansion is so small that the difference between the real and apparent specific heats is small. Nevertheless, it exhibits itself in experiments for determining specific heats, by showing an increase of specific heat as the expansion increases. Tables VII. and VIII. illustrate this fact.

If the mean specific heats are taken between 32° and 212°, they will be as shown in the first column; and if between 32° and 540° F., the results are given in the second column.

TABLE VII.—SPECIFIC HEATS.

	Mean between 32° and 212°.	Mean between 32° and 540°.
Iron	0·109	0·1218
Mercury	0·0330	0·0350
Zinc	0·0927	0·1015
Antimony	0·0507	0·0549
Silver	0·0557	0·0611
Copper	0·0949	0·1013
Platinum	0·0355	0·0355
Glass	0·1770	0·1990

For water, the increase of specific heat is

$$\begin{aligned} C = \text{spec. heat} &= 1\cdot0000 \text{ at } 0° \text{ Centigrade.} \\ &= 1\cdot0042 \text{ ,, } 50° \text{ ,,} \\ &= 1\cdot0132 \text{ ,, } 100° \text{ ,,} \\ &= 1\cdot0262 \text{ ,, } 150° \text{ ,,} \\ &= 1\cdot0440 \text{ ,, } 200° \text{ ,,} \\ &= 1\cdot0568 \text{ ,, } 230° \text{ ,,} \end{aligned}$$

For gases it has been explained that the term B disappears, and the expression above reduced to

$$Q = \frac{1}{772}(A + C).$$

If now the gas be kept at constant volume, no expansion will occur, and the term C will also disappear, and the whole effect of a transfer of heat to the body will be to cause an increase, A. But if, in addition to the same change in A, the gas expands and performs work represented by C, the specific heat will be greater. This is called the apparent specific heat of the gas, and the specific heat under constant volume the real specific heat.

The results of experiments by Regnault to determine the specific heats of gases at constant pressure, are given in Table VIII. for the substances named;—

TABLE VIII.—SPECIFIC HEATS AT CONSTANT PRESSURE.

Air	0·2377
Oxygen	0·2182
Nitrogen	0·2440
Hydrogen	3·4046
Carbonic acid	0·2164
Carbonic oxide	0·2479
Marsh gas	0·5929
Ammonia	0·5080
Sulphuric acid	0·1553

For specific heats of gases at constant volume direct experiments are difficult, and they have been determined only by indirect methods. Let C be the specific heat of a gas at constant pressure, and C′ the specific heat at constant volume: the value of the ratio $\frac{C}{C'}$, may be determined by various methods. The results of these methods indicate that for air the ratio is $\frac{C}{C'} = 1\cdot410 = k$, the exponent employed in the formulæ given for the expansion of gas in a previous paragraph.

For steam in the perfectly gaseous state, according to Rankine the ratio is $\frac{C}{C'} = 1\cdot304$, and according to others, $\frac{4}{3} = 1\cdot333$.

The specific heat of air under constant volume, found in this manner, is $0\cdot169$.

The difference between $0\cdot2377$, the specific heat at constant pressure, and $0\cdot169 = 0\cdot069$, is really the latent heat of expansion of air for 1° at 32° F.

By comparing the work due to the expansion of air, in foot-pounds, with this quantity $0\cdot069$, a theoretical verification of the mechanical equivalent of heat may be found.

Let one pound of air be subjected to a change of heat corresponding to 1° F., first under constant pressure, and then under constant volume. According to the expression $q = \frac{A + C}{E}$, which represents, generally, the dynamic equivalent of heat, we shall have, in the first case,

$$q \times E = A + C;$$

and in the second, since C disappears, being the work due to expansion, we have

$$q \times E = A,$$

and

$$(q - q')\,E = A - A + C = C.$$

$q - q'$ is the difference, in units of heat, between the quantities of heat necessary to raise 1 lb. of air 1°, under the conditions of constant pressure and constant volume, and will be represented, according to the corresponding values of the specific heats, by

$$0\cdot069 \times 1^\circ \text{ units of heat,}$$

and we shall have

$$0\cdot069 \times 1^\circ \times E = C = \text{work of expansion.}$$

But we have from Mariotte and Gay-Lussac's law

$$P\,V = 53\cdot35\,T,$$

and

$$P\,V' = 53\cdot35\,T',$$

and

$$P\,(V - V') = 53\cdot35\,(T - T') = 53\cdot35 \times 1^\circ.$$

But P, the external pressure, × by the change of volume, is the work of expansion = C.

Hence

$$C = 53\cdot35 \times 1^\circ;$$
$$0\cdot069 \times 1^\circ \times E = 53\cdot35 \times 1^\circ;$$
$$0\cdot069 \times E = 53\cdot35;$$

and

$$E = \frac{53\cdot35}{\cdot069} = 773\cdot2.$$

This is a theoretical dynamic equivalent of heat depending on the law of Mariotte and Gay-Lussac, and the values of specific heats found by experiment.

Actual direct determinations of this equivalent have been made by different investigators, with the results given at p. 709.

The number $772\cdot69$, determined by Joule, is regarded as the most satisfactory, and 772 has been adopted as the equivalent in English measures, and is often called Joule's equivalent. Compared with the above theoretical determination, we have

Theoretical	E = 773·2
Experimental, by Joule	E = 772·69
Difference	0·51 ft.-lb.

It has been found impossible to determine, theoretically, the relation which the temperatures bear to the pressures, and, upon this point, reliance is placed mainly on the celebrated experiments of Regnault. On account of the universal employment of steam in practical applications, the importance of the results can hardly be sufficiently estimated. Regnault's Tables, in fact, constitute the basis of all theoretical applications of heat through the medium of steam; giving, as they do, in exact figures, the elastic force of saturated steam for all usual temperatures.

These Tables show that no simple relation exists between the maximum tension and the temperature. Different empirical formulas have been proposed, however, to express this relation with certain degrees of approximation.

The specific heats of the vapours of water, alcohol, and ether, as determined by Regnault, are given in the following tabular form, together with the densities at 32°, and at one atmospheric pressure;—

	Density, air being unity.	Specific Heats.
Vapour of water	0·622	0·4750
„ alcohol	1·589	0·4513
„ ether	2·556	0·4810

In regard to the specific heats of bodies, it is maintained by Clausius, that the true or real specific heat of a body would be constant, if the volume were kept constant for all states, solid, liquid, and gaseous.

Rankine maintains, on the other hand, that the real specific heats remain constant, if there is no change of volume, only so long as the substance retains the same state, solid, liquid, or gaseous; and that a change of specific heat occurs with a change of state, even though there is no change of volume. It is difficult to decide such a question experimentally, but the views of Clausius appear to be most in accordance with the dynamic theory of heat.

The combustion of bodies in air being to a certain extent a self-sustaining process, it is only necessary to supply the elements of combustion, fuel and air, in proper proportions, and to ignite the combustible at one point, in order to produce heat at will, and in any desirable quantities. And the elements necessary being almost universally distributed, or at least readily procurable, there are scarcely any circumstances in which the evolution of heat for useful purposes is not practicable.

For the purposes of heat-power it is not advisable, however, except in some small heat-engines, to employ the heated products of combustion directly in the cylinders of engines; and hence the necessity of transferring the heat of combustion to water, or some other liquid, as the medium through which the heat is utilized. Watery vapour is that which is universally used, not only on account of the favourable properties of this vapour, but also from the universal distribution and cheapness of the liquid, the expense of procuring it being comparatively small.

The apparatus for producing steam under the circumstances required for use must combine, therefore, the conditions necessary for the supply of water, the transfer of the heat of combustion to the water, and the retention of the steam produced.

The full discussion of these conditions, in the case of the steam boiler, involves the construction and arrangement of the parts of the boiler, and cannot be disconnected from them; but there are certain general principles of physics which form the basis of such construction and arrangements, which may be first enumerated in a general way, such as the laws of transfer of heat, the temperature of the products of combustion, and the laws of conduction. The transfer of heat from a heated body to one that is at a lower temperature consists, according to the dynamic theory of heat, in the loss of living force, due to heat-motion, in the hotter body, and an equivalent gain of living force in the colder body. When the two bodies are quite distinct, or separated, and do not form part of one and the same body, this transfer takes place generally, as has been stated, through the intervening ethereal medium by the process of radiation. Through this medium there is a tendency to equilibrium of temperature, or of living force, the relative exchange of temperatures being inversely proportional to the masses of the bodies.

It is probable that the transfer of heat between two bodies is always thus accomplished by radiation, although, technically, a distinction is made between the transfer at appreciable distances, or radiation, and the transfer by actual contact of the two bodies.

Heat may be transferred practically also by the actual change of position of the body in which it exists. In this mode of transfer, which is called convection, or carrying, the transfer is a mechanical one, and is not in any way connected with the change of heat in the body carried. Although this mode of transferring heat is of great importance in the arts, and especially in connection with the generation of steam, involving as it does the question of the circulation of heated fluids, yet after the convection of heat by the transfer of the body in which it exists, whether that body be solid, liquid, or gaseous, there still must take place the transfer from the heated body to another, by the process of radiation or contact, before the heat can be utilized as heat. Thus a heated gas or liquid may be carried through pipes, or may be mingled mechanically with other gases or liquids for the purpose of conveying heat; but the final process by which that heat is actually transferred from the heated gas or liquid to another body, as heat, must depend on the dynamic laws of heat.

In adopting, therefore, the usual designations, radiation, contact, and convection, of the modes by which heat is transferred, it is to be understood that the latter is a mechanical mode, and need be discussed only in connection with the carrying of bodies, to the places or points at which it is desirable or necessary for them to impart their heat to other bodies. A heated particle of a substance communicates vibrations to the ethereal medium, whether the particle be surrounded by air or whether it be in a vacuum. In ordinary language, the particle sends rays of heat in every direction; these rays or waves proceed indefinitely, without change in strength or character, and with the same velocity as light, until they are intercepted by some body in the paths of the rays. If such a particle be a molecule on the surface of a body, it is evident that it will send off rays of heat in every direction not intercepted by the body itself.

It is a common error to suppose that the intensity of a ray of heat diminishes, as the distance between the body emitting and the body receiving the heat increases—that is, inversely as the square of the distance. The same popular error exists to a certain extent in regard to the force of gravitation; whereas the greatest conceivable distances have apparently no effect in retarding or diminishing the effects of the influences called heat and gravitation. The law of the inverse squares of the distances is rather a geometrical than a physical law, and refers to the action of one body on another, whether the question be one of heat or gravitation.

A body or collection of molecules possessing a certain amount of living force, due to heat, imparts this energy to the ethereal medium in all directions, and the quantity of energy intercepted by another body will depend on the distance between the two bodies; the quantity thus intercepted by the same body at different distances being inversely proportional to the squares of the distances.

This purely geometrical law may be illustrated by supposing a heated body to be giving off radiant heat in every direction. Another body, a plate for instance, placed at regular distances from the heated body, will intercept less of this heat as it is removed from the heated body, the number of rays, or quantity of heat, intercepted at two different distances being, from the geometrical conditions of the problem, inversely proportional to the squares of those distances.

The absurdity of supposing that, because the mathematical result of reducing the distance to zero is a symbol of infinity, therefore the physical influence at that distance is infinite, need not be discussed, although such an assumption is often made in attempts to discuss the intensity of molecular forces. When, therefore, it is said that the intensity of radiant heat varies inversely as the square of the distance, all that is meant is, that the same body, placed at different distances from the same source of heat, will receive, in a given time, by radiation, different quantities of heat in the inverse proportion of the square of the distances. In going away from a glowing fire, for instance, we receive less and less heat, because, as the distance is increased, we pass out of the paths of large numbers of divergent rays which would otherwise reach us.

The inclination of the surface which intercepts radiant heat determines, for similar reasons, the quantity of radiant heat received. Even if the rays be supposed parallel, as in the case of the radiant heat of the sun, it is apparent that all the heat conveyed by a beam of rays may be represented by the section of the beam perpendicular to its direction. If the beam falls upon a surface inclined to its direction, the amount of surface over which the beam will be distributed will be greater as the inclination of the surface is greater. If the surface be plane when it becomes parallel to the axis of the beam, it will receive no heat.

Hence in estimating the intensity of radiant heat by units of surface, the inclination of the receiving and absorbing surfaces must be considered.

The regions of the earth's surface near the poles, from their approach to parallelism with the direction of the sun's beams, receive less heat on each square mile than at the tropics. If a heated body be placed within an enclosed space, it is evident that although some parts of the enclosure may receive more heat a square foot than others, yet all the heat emitted will be absorbed. All the heat emitted by radiation from the incandescent fuel, on the grate of the furnace of a steam boiler, is thus absorbed by the side walls and crown of the furnace, though in different proportions a square foot.

Attempts have been made to determine the quantity of heat, in units of heat, emitted by any given surface at a given temperature, supposing the temperature of the absorbing surfaces to remain at constant temperature. Dulong and Petit made numerous experiments on this subject, which resulted in the determination of certain general laws. The experiments were made to determine the rate of cooling of bodies in an enclosed space, the space being filled with different gases, and the enclosure being maintained at constant temperature.

The results were enunciated as follows;—

"The cooling of a body results from radiation and from contact of the fluid or gas which surrounds it."

"The rate of cooling, from radiation alone, is the same for all bodies at the same temperature, but its absolute value depends on the nature of the surfaces."

It is represented by the following formula;—

$$q = C \cdot a^t (a^{t_1} - 1) \text{ or } q = C_1 (a^{t_1} - 1);$$

in which q represents the number of French units of heat, emitted by one unit of surface in a unit of time, C a constant depending on the nature of the surface of the radiant body, a the number 1·0077, t the temperature of the enclosure or absorbent, and t_1 the excess of temperature of the radiating body over the absorbing body in degrees Centigrade. The rate of cooling by contact of a fluid surrounding the heated body is also the same for all heated bodies, but its absolute value does not depend on the nature of the surface, but only on the form of the heated body.

For air under ordinary atmospheric pressure, the law of cooling by contact is expressed by the formula

$$q = C' t^{1 \cdot 233};$$

in which q represents the quantity of heat in calories, abstracted from one unit of surface by the air, in a unit of time, C′ a constant depending on the form of the surface, and t the excess of temperature of the body over that of the air surrounding it.

These general laws were confirmed by Peclèt, who made many experiments to determine the constant coefficients of the formulas. Similar experiments have more recently been made also by Hopkins, whose results are as follows, for radiation alone;—

Glass, $q = 9 \cdot 566\, a^t (a^{t_1} - 1)$; dry chalk, $q = 8 \cdot 613\, a^t (a^{t_1} - 1)$; dry new red sandstone, $q = 8 \cdot 377\, a^t (a^{t_1} - 1)$; polished limestone, $q = 9 \cdot 106\, a^t (a^{t_1})$. In which q represents the quantity of heat emitted in one minute from one square foot of surface, in terms of a unit which is the quantity of heat required to raise the temperature of 1000 grammes of water 1° C.

Hopkins also determined by experiment the constants in the formula for the cooling power of gases by contact; it may be doubted, however, whether the experiments were made in such a manner as to lead to results of practical value. The constants determined by Peclèt and by Hopkins can only refer to the special conditions under which the experiments were made, which are not those admitting of general application. Moreover, the separating of the influences of radiation and contact in the experiments, does not seem to have been sufficiently complete.

The only results of value seem to be the general laws, as enunciated, without reference to quantities of heat.

The relative radiating powers of different surfaces at 180° F., as determined by Leslie, are represented approximately in Table IX.

It is stated by Magnus that the greater or lesser density of the surface has no influence on radiation from the surface. Platinum which has been strongly hammered, possesses the same emissive power as platinum carefully annealed. But the same surface roughened with emery-paper has its emissive power greatly increased. As far as quantities of heat are concerned, it is doubtful whether anything further than such relative determinations can, in the present state of

knowledge, be depended on; the actual or absolute quantities for different temperatures being still uncertain.

TABLE IX.—RADIATING POWERS OF SURFACES.

Lamp-black	100	Mica	80
Paper	98	Graphite	75
Resin	96	Tarnished lead	45
Sealing-wax	95	Mercury	20
Crown glass	90	Polished lead	19
Indian ink	88	Polished iron	15
Ice	85	Tin plate	12
Red-lead	80	Gold, silver, copper	12

Experiments by Magnus give the following relative emissive powers for different surfaces at 270° F.

Blackened silver	100	Rock salt	13
Glass	64	Polished silver	9·7
Fluor-spar	45·5		

The laws of radiation which have been enunciated point out, however, one fact which has an important bearing in connection with the transfer of heat. The formula $q = C \cdot a^t (a_1^t - 1)$ shows that the differences of temperatures of the radiant and absorbing bodies, enter as exponents in the formula, so that with a constant temperature of the absorbent body, such as the water over the furnace in steam boilers, the quantity of heat emitted by the grate, and absorbed by the water, will increase with great rapidity as the temperature of the fire increases. The formula for the cooling of the gaseous products of combustion, on the other hand, $q = C' t_1^{1 \cdot 233}$, shows, if this law be true, that the influence of increase of temperature in the gases is not so great as in radiation, because the difference of temperature between the heated gases and the water of the boiler, is simply raised to the power indicated by the constant exponent 1·233.

Light and radiant heat are now assumed by philosophers to be manifestations of the same physical agent; and heat, like light, when it falls upon the surface of a body, may be reflected, refracted, absorbed, or polarized. The radiating powers of different bodies, or different surfaces, represent also their absorptive powers, and radiant heat does not affect the eye, or solids do not become luminous, until the temperature reaches about 750° F.

The radiation and absorption of gases, according to Tyndall, present very peculiar laws, and our knowledge of the action of gaseous bodies on radiant heat is still very slight. It has been demonstrated experimentally that a ray or beam of heat is wholly, or almost wholly, transmitted through moderate distances in air, oxygen, hydrogen, and nitrogen; and conversely, no radiation takes place from the heated particles of these gases. The only mode, therefore, by which heat can be imparted to these gases, or by which they can impart heat to other bodies, is by actual contact. Some other gases possess remarkable powers in absorbing or intercepting dark radiant heat.

The absorption of radiant heat by vapour of water diffused in air, under circumstances of average humidity, is seventy times greater than the absorption by dried air. As the quantity of watery vapour is increased, the amount of heat absorbed is also increased.

This fact has been suggested by C. E. Emery, of New York, to be an important cause of loss of heat in the cylinders of steam engines, when there is condensation in the cylinder. The walls of the cylinder radiate heat to the cloudy vapour and become cooled, the heat radiated being carried out with the exhaust; and when new steam is again admitted, the walls are again reheated by the incoming steam.

Comparative experiments, made with glass and iron cylinders, seem to confirm this view, glass being a feeble radiator and absorber. Acting on this idea, Emery proposed a mechanical separator to the double cylinder engine, to remove the particles of water from the steam in its passage from the smaller to the larger cylinder.

The quantity of watery vapour contained in air at different temperatures is often a matter of importance, especially when taken in connection with the radiation of heat. Table X. shows the quantities of watery vapour in air at dew points from 0° to 100° F.

The fact that air charged with moisture absorbs, in each unit of time, seventy times more heat than air practically dry, is an explanation of a phenomenon which has an important bearing on human health and comfort. When air at a high temperature is overloaded with moisture, radiation takes place from the air to the body, producing an oppressive sensation of heat. When, on the other hand, the temperature of saturated air is lower than the natural temperature of the body, the radiation or transfer of heat will take place from the body to the air, producing the sensation of cold.

It is this that makes a low temperature, with a dry atmosphere, more bearable than a higher temperature with air highly charged with moisture.

Definite knowledge on the transfer of heat by contact, in reference to quantities of heat, would be of greater value, practically, than a knowledge of the exact laws of radiation, because in nearly all cases the quantity of radiating surface, in the evolution of heat by combustion, depends on the quantity of incandescent surface of the fuel, the size of furnace, and form of bed of fuel; which quantities are dependent on the quantity of heat required an hour, and are thus fixed by other conditions than the laws of radiation. But the utilization of the heat in the gaseous products of combustion, requires special constructions of flues and pipes which, while conveying these gases to the chimneys, act at the same time as heating surfaces for liquids in contact with the surfaces.

When heated gases, or liquids, are conveyed in pipes or conduits to the places where the heat is to be given off, by contact or radiation from metallic surfaces, the utilization of heat involves the

laws of transfer by contact, and the determination of the necessary amount of surface in such case is often directly dependent on these laws. The quantity of heating surfaces of steam boilers, the cooling surfaces of condensers, the quantity of surface of hot-water pipes for heating air for dwellings and factories, questions which are continually presented to the engineer, are dependent on the action of these surfaces in transferring, by contact, the heat of a liquid or gas on one side of a surface, to a liquid or gas on the other side.

TABLE X.—QUANTITIES OF WATERY VAPOUR IN AIR.

Deg. Fahr.	Grains in a Cubic Foot.	Deg. Fahr.	Grains in a Cubic Foot.	Deg. Fahr.	Grains in a Cubic Foot.	Deg. Fahr.	Grains in a Cubic Foot.	Deg. Fahr.	Grains in a Cubic Foot.
0	0·186	20	1·563	40	3·066	60	5·828	80	10·732
1	0·810	21	1·618	41	3·168	61	6·013	81	11·055
2	0·836	22	1·674	42	3·274	62	6·204	82	11·388
3	0·864	23	1·733	43	3·382	63	6·400	83	11·729
4	0·893	24	1·793	44	3·495	64	6·620	84	12·079
5	0·925	25	1·855	45	3·610	65	6·810	85	12·439
6	0·957	26	1·915	46	3·729	66	7·024	86	12·808
7	0·992	27	1·986	47	3·851	67	7·243	87	13·185
8	1·028	28	2·054	48	3·979	68	7·469	88	13·577
9	1·065	29	2·125	49	4·109	69	7·702	89	13·977
10	1·103	30	2·197	50	4·244	70	7·941	90	14·387
11	1·143	31	2·273	51	4·382	71	8·186	91	14·809
12	1·184	32	2·350	52	4·524	72	8·439	92	15·241
13	1·226	33	2·430	53	4·671	73	8·699	93	15·684
14	1·270	34	2·513	54	4·822	74	8·966	94	16·140
15	1·315	35	2·598	55	4·978	75	9·241	95	16·607
16	1·361	36	2·686	56	5·138	76	9·523	96	17·086
17	1·409	37	2·776	57	5·303	77	9·813	97	17·577
18	1·459	38	2·870	58	5·473	78	10·111	98	18·081
19	1·510	39	2·996	59	5·648	79	10·417	99	18·598
								100	19·129

It may be regarded as a rule, that when the liquids or gases on the opposite sides of a metallic plate remain at constant temperatures respectively, the thickness of the plate does not affect the rate of transfer of heat from one side to the other. It is only when the temperatures of the fluids on the opposite sides are changing, that the internal conductivity of the wall between them, or the dissipation of heat by the wall, need be considered.

Thus the influence of the thickness of the metallic flues of a steam boiler is felt only in retarding the rapidity of first generating steam after the fires are started. After the boiler is working steadily at a given pressure, the greater or lesser thickness of the metallic plates which transmit the heat to the water, is a matter of little importance, as far as the rate of transfer is concerned. This fact has been demonstrated both by experiment and by direct observation.

The following empirical formula gives, approximately, the rate of transfer of heat an hour, for each square foot of heating surface of the tubes or flues of steam boilers;—

$$q = \frac{(t_1 - t)^2}{a};$$

in which $t_1 - t$ is the difference of temperature between the heated gases on one side at any point, q the quantity of heat transferred in units of heat, and a a constant, the value of which lies between 160 and 200.

This formula is intended only as a rough approximation. As it is stated by Rankine to be the result of experiments on the evaporative powers of boilers, it is probably applicable only to the special conditions of these experiments.

If we regard the water in the boiler as the absorbent of the heat, the sides of the flues being the walls of the chambers which separate the water from the heated gases, the application of the law of Dulong and Petit, would give the quantity transferred by each square foot in an hour as follows;—

$$q = C \,.\, (t_1 - t)^{1 \cdot 233};$$

differing from Rankine's formula only in the exponent.

All that is known definitely on this subject, at present, appears to be that the transfer is proportional to the difference of temperature raised to a power greater than unity, probably between 1 and 2.

The greatest difficulty in applying either law, lies in the indeterminate constant coefficient. In all cases of heating or cooling a fluid by contact with a surface, the quantity of heat transferred in a unit of time, depends on the circulation of the fluid, and where one fluid is heated or cooled by another, the two being separated by a metallic plate, the circulation of both must be taken into consideration. This is the condition under which the heat of the gaseous products of combustion in the steam boiler is transferred to the water. Want of circulation in either the heated gases or the water, causes a retardation or complete suspension of the transfer of heat.

When heat is thus transferred by contact from one fluid, either liquid or gaseous, to another through a metallic plate, it results from the law that the quantity transferred depends on the

differences of temperatures, that the motions of the two fluids should be in opposite directions. The difference of temperatures will then be the greatest possible at every point.

Heating surface is an expression used to designate in mechanical constructions the surfaces or plates, usually metallic, through which heat is transmitted. Where the transfer is by the contact of a fluid, as in the flues of steam boilers and cooling surfaces of condensers, the heating or cooling fluid is supplied in a continuous current, or stream, through the flues or pipes. In such cases the fluid usually issues from the apparatus at a constant determinate temperature. This temperature will depend on the initial temperature and the specific heat of the fluid, and the total quantity of heat transferred from or to the fluid, as it passes through the apparatus, will be represented by the following expression;—

$$q_1 = C_1 (t_1 - t) \times W;$$

in which q_1 represents now, not the heat transferred from a particular square foot of surface in a unit of time, but the whole heat abstracted from, or imparted to, the circulating fluid in a unit of time; $t_1 - t$ represents the loss or gain of temperature of this fluid, and W the total weight of the fluid which passes through the apparatus in a unit of time.

The volume of fluid which passes through the apparatus, will be proportional to the velocity multiplied by the total sectional area of the flues or pipes through which it passes; and since the weight is equal to the volume, multiplied by the density, or $W = V\,D$, it is evident that it will require a much greater volume of a gas, than of a liquid, to impart or abstract a given quantity of heat if a given quantity of heat is to be transferred by an apparatus, through the medium of fluid contact in a given time, that quantity being represented by

$$q_1 = C_1\,W\,(t_1 - t)$$

or

$$q_1 = C_1\,V\,D\,(t_1 - t).$$

It appears, therefore, that the volume of the fluid, its density, its specific heat, and the initial and final temperatures, must all be considered. Where the initial and final temperatures of the circulating fluid are fixed by the conditions of the problem, the quantities to be considered will be the specific heat, the volume, and the density of the fluid. For given volumes of flow, liquids are therefore, under such conditions, more efficient than gases in proportion to their greater density.

Conduction of heat refers to the transmission of heat, from one part of a continuous and homogeneous body to another part of the same body. When a body is heated at one point, the heat is transmitted with greater or less rapidity throughout the whole mass, depending on the nature of the body, and the differences of temperature of the heated part and other parts of the body. If the body is terminated by two parallel surfaces, which are each kept at a constant temperature, heat will pass at a constant rate from the hotter surface to the other by conduction.

The law of conduction under these circumstances is, that the quantity transmitted for a unit of area, perpendicular to the direction of transmission, and for a unit of time, is directly proportional to the difference of temperatures of the parallel surfaces, and inversely proportional to the thickness, or distance, which separates the two surfaces. If t_1 and t represent the temperatures of the two surfaces, and e the distance separating them, the quantity of heat transmitted will be

$$q = \frac{C\,(t_1 - t)}{e}.$$

The coefficient C depends on the nature of the body.

When the quantities of heat thus transmitted, for different bodies, across an interval one unit of length in thickness, and for one unit of area and time, are determined, these quantities of heat represent the relative conductibilities of the substances, and the numbers thus found, when referred to one as a standard, are called the conductivities of the different substances.

The relative conductivities of metals determined by experiments on bars of a given cross-section, the transmission of heat being determined by thermometers, placed at different distances in holes drilled in the bars, have been ascertained by different investigators.

Table XI. of conductivities is from experiments made by Wiedemann and Franz, the temperatures along the bars being determined by a thermo-electric arrangement.

TABLE XI.—CONDUCTIVITIES OF METALS.

Name of Metal.	Relative Conductivities.	
	In Air.	In Vacuo.
Silver	100·0	100·0
Copper	73·6	74·8
Gold	53·2	54·8
Brass	23·6	24·0
Tin	14·5	15·4
Iron	11·9	10·1
Steel	11·6	10·3
Lead	8·5	7·9
Platinum	8·4	7·4
Palladium	6·3	7·3
Bismuth	1·8	..

It was found that the conductivity diminishes as the temperature of the metal increases. For iron, the diminution of the number representing the conductivity was from 15 to 25 per cent. for an increase of 100° temperature. It was shown also by Forbes that the same numbers show the relative conductivity for electricity.

For the absolute quantities of heat, in thermal units, transmitted, the following Table XII. gives reliable data for a few substances. In this table the numbers and formulas give the quantities of heat in calories which will pass through a metallic plate 1 millimetre in thickness and 1 square metre in area in 1 second, when the temperatures of the two parallel surfaces differ by 1° Centigrade.

TABLE XII.—ABSOLUTE CONDUCTIVITIES OF METALS.

Name of Substance.	Observer.	
	Ångström.	Neumann.
Copper	$102 \cdot 7\,(1 - 0 \cdot 003567t)$	110·75
Zinc	.. ..	30·70
Brass	.. ..	30·19
Iron	$19 \cdot 88\,(1 - 0 \cdot 00479t)$	16·37
German silver	.. ..	10·94
Lead	By Peclèt	3·84

The results of Neumann, reduced to English units of heat and English units of area, thickness, and time, will give the approximate numbers in the following table for the quantity of heat transmitted a second, by conduction, through an area of 1 sq. ft., and a thickness of 1 millimetre, or ·0394 of an inch, the difference of temperatures between the parallel faces of the plate being 1° F.;—

Copper	41·2	Iron	6·1
Zinc	11·4	German silver	4·1
Brass	11·2	Lead	1·4

The relative thermal resistance, or reciprocal of the conductivity of liquids, as determined by Guthrie, is given in the following table for the liquids named;—

Water..	1·0	Sperm oil	8·85
Glycerine	3·84	Alcohol	9·09
Acetic acid	8·38	Oil of turpentine	11·75

The absolute values of the conductivities of liquids are uncertain. It was ascertained by Guthrie, however, that the conducting power of liquids is greater at high than at low temperatures. And when there is no convection of heat in liquids, by which heated particles are carried from one point to another, the conducting power of liquids is very small; the conducting power of water being, according to Depretz, only about $\frac{1}{100}$ that of copper.

Gases possess such a feeble power of conduction that they have been regarded as not possessing this property. Experiments by Magnus, and theoretical deductions by Clausius, however, demonstrate that in perfect gases there is a slight conduction. Clausius estimates the conducting power of air to be about $\frac{1}{1400}$ that of lead.

The calorific intensity of combustion, or degree of temperature of the products of combustion, and of the solid incandescent combustible, seems to depend on the rapidity of combustion rather than the quantity of heat evolved. Nearly all writers on the subject have given a method for finding what may be called the theoretical temperature of combustion, by supposing that all the heat evolved is contained in the gaseous products, and calculating the temperature by means of the specific heats, and the weight of the products of combustion, and the heat evolved, making use of formulas corresponding to that which has been given at pp. 719, 720.

Such determinations, however, have but little practical value for solid combustibles, because the residual incandescent solid gives off rapidly, by radiation, heat which does not pass off with the gases. The amounts of heat thus given off for different solid combustibles, in parts of the whole heat evolved, are, according to Peclèt, as follows;—

For Coal	0·55	For Charcoal	0·55
„ Coke	0·55	„ Peat	0·25
„ Wood	0·29	„ Peat-charcoal	0·48

The quantity of heat radiated from an incandescent combustible depends, not only on the temperature of the combustible, but also on the temperature of the absorbent, and the nature of the surfaces. On this account there does not appear to be sufficient ground for ascertaining the temperatures of furnaces, or of the escaping gases, by this process. It is well known from common observation, that the temperature in ordinary furnaces is greatly increased by a more rapid supply of air; so that the quantity of heat evolved in a given time, and the temperature, are thus increased.

Chemical action is promoted by high temperatures, and the conditions for increase of temperature, increase of heat evolved in a given time, and rapidity of chemical action, are coincident. Where excessively high temperatures are desirable, as in blasting furnaces, and in melting metals, the substance to be melted is placed in contact with the fuel, and all external radiation prevented.

Under these circumstances air may be supplied in large quantities by artificial draught to the combustible.

In open furnaces, however, where a part of the heat is to be transferred by external radiation as the combustion proceeds, too much air may be hurtful, by chilling the combustible and diminishing the activity of the fire. In all cases, complete or perfect combustion requires a fixed quantity of air, any excess being hurtful. The quantity supplied in a unit of time, must depend on the surface of the combustible exposed to incandescence or inflammation, and the rapidity of combustion.

Actual observation by a thermometer or pyrometer is, therefore, the only reliable means of ascertaining the temperatures which accompany combustion.

The quantity of water which a steam boiler will evaporate in a given time depends, primarily, on the temperatures to which those parts of the plates of the boiler known as heating surfaces, are exposed, and to the extent of those surfaces. In the furnace, the crown and side-walls are exposed to the radiant heat of the incandescent fuel, and to the contact of the heated gases. The heating surfaces of the flues are usually exposed to the contact of the heated gases alone.

The temperature of the fuel, and the initial temperature of the heated gases, depend on the intensity of combustion, or the quantity of fuel burned on each square foot of the grate-surface in a unit of time, and also on the kind of combustion that takes place: perfect combustion, in this connection, designating that in which no combustible gases or uncombined oxygen escape to the chimney. For the transfer of heat in the furnace by radiation, if G represent the number of square feet of grate-surface, and q the quantity of heat emitted from each square foot in a unit of time, the quantity of heat transferred, according to the laws of Dulong and Petit, will be

$$Q_1 = q\,G = C\,a^t\,(a^{t_1} - 1)$$

$$\text{or} \qquad Q_1 = C_1\,(a^{t_1} - 1).$$

The transfer of heat by contact of the heated gases in the furnace will be represented by

$$Q_2 = FC_2\,t_1^{1\cdot 233},$$

in which F represents the total furnace surface, and the total transfer of heat in the furnace will be

$$Q_1 + Q_2 = C_1\,(a^{t_1} - 1) + FC_2\,t_1^{1\cdot 233}.$$

In this expression, t_1 represents the difference between the temperature of the incandescent fuel, and the temperature of the water in the boiler. If t_w represent the temperature of the water in the boiler, the temperature of the gases as they enter the flues will be $t_1 + t_w$. From this initial point, the temperature of the gases will diminish, until they leave the heating surface in their course to the chimney. The law of this diminution may be thus found: Let q_1 represent the quantity of heat transferred, at any point of the heating surface, through one square foot, in one unit of time, the difference of temperature at that point being t. The quantity transferred through a portion of the heating surface represented by $d\,s$ will be $q_1\,d\,s$.

The reduction of temperature which the gases undergo, in a unit of time, in passing that surface, will be $d\,t$, and the quantity of heat lost by the gases will be represented by C W dt, C representing the specific heat of the gases, and W the weight of gas which passes the element $d\,s$ in a unit of time. The quantity of heat transferred to the water must be equal to that lost by the gases, and hence we have

$$q_1\,d\,s = C\,W\,dt$$

$$d\,s = \frac{C\,W\,dt}{q}.$$

Substituting for q its value as given by the laws of Dulong and Petit, we have

$$d\,s = \frac{C\,W\,dt}{C_2\,t^{1\cdot 233}}.$$

Integrating this expression between the limits t_1, the initial temperature t_2, the temperature of the gases as they leave the flues, we have

$$S = \frac{C\,W\,(t_1^{-\cdot 233} - t_2^{-\cdot 233})}{-\cdot 233\,c_2},$$

from which the value of t_1 may be found.

$$t_1 = \left(\frac{C\,W\,t_2^{\cdot 233}}{C\,W - \cdot 233\,c_2 s t_2^{\cdot 233}}\right)^{\frac{1}{\cdot 233}}.$$

In this expression s represents the whole heating surface of the boiler.

This expression is of no special practical value, but serves to indicate a mode by which the initial temperatures may be found. The temperature t_2 of the gases as they leave the flues may usually be observed by a common thermometer, and it would only be necessary to make experiments for ascertaining the value of W, and the constants which enter the equation.

If the initial temperature could be observed, or calculated with certainty, the quantity of heat imparted to the water through the heating surfaces of the flues might be found, being represented by

$$Q_3 = C\,W\,(t_1 - t_2).$$

If the expression $d\,s = \dfrac{C\,W\,dt}{C_2 t^{1\cdot 233}}$ be integrated between the limits t_1 and O, which supposes that the flues extend far enough, to reduce the temperature of the gases to the same temperature as the

water, we should obtain equations by which the relations between q and s, and t and s, become known, namely:—

$$t = C_3 \frac{1}{s^{4 \cdot 3}}\ q = C_4 \frac{1}{s^{5 \cdot 3}}$$

C_3 and C_4 being constants, and s being expressed in units of length of the flues, one unit being the length which corresponds to a segment which is equal to one square unit of area.

The corresponding formulas, if we assume with Rankine that $q = At$, will be

$$t = -\frac{A\,C\,W}{s}$$

$$q = \frac{A\,C^2\,W^2}{s^2}.$$

These formulas show that after the gases enter the flues, the temperatures diminish very rapidly, and that the quantity of heat transferred through each square foot of surface diminishes by one formula as the fifth power, and by the other as the square, if the distance from the initial point increases. The relative efficiency of heating surfaces in passing towards the chimney may thus be estimated. Increase of heating surface should be made as near to the furnace as possible, and not by adding length at the extreme end towards the chimney.

The effects which follow the transferring of heat to a body, solid, liquid, or gaseous, have been described at p. 715.

The term latent heat is a technical expression, designating a quantity of heat which has apparently disappeared, but which really has been employed in producing changes in the body, in the form of work, other than the change of velocity of molecular motion, or change of temperature. By reversing the process by which heat is thus made to disappear, this latent heat may be reproduced.

In separating the effects of a given quantity of heat q into the parts A, B, and C, the true theories of the coefficient of expansion, specific heat, and latent heat become susceptible of rational explanation. Of these quantities, A and C, for any change of heat in a body, can usually be numerically estimated; the change A being directly proportional to T, the change of absolute temperature, and the change C being the product of the external pressure multiplied by the change of volume of the body. The quantity B, however, cannot thus be separately calculated, because there is not, in the present state of science, sufficient knowledge of molecular attractions to compute directly the work performed in overcoming these attractions, for a given change of volume. This is not important, however, because this quantity may be found from the expression given at p. 719, when q, A, and C are known. And in the action of bodies under the influence of heat in the solid and liquid forms, for nearly all bodies, the quantity C is so small for the extreme range of temperature belonging to those states, that for technical purposes it may be neglected; while, on the other hand, after the body has passed to the state of vapour or gas, the quantity C becomes large, and the quantity B so small that it may be neglected.

The latent heat which, in the most general case, is represented by $\frac{1}{772}$ (B + C) becomes for solids and liquids, practically, $\frac{1}{772}$ B, and for gases, especially perfect gases, $\frac{1}{772}$ C. In other words, in the case of solids and liquids, for all practical purposes, the effect of the exterior pressure may be neglected, and in the case of perfect gases and vapours, the internal work may be regarded as simply confined to the change of molecular vibration.

The specific heat of a solid or liquid may be regarded, therefore, as equivalent to

$$c = (a + b)\frac{1}{772}$$

$\frac{a}{772}$ being the quantity of heat, in units of heat, which remains in 1 lb. of the substance, after an increase of temperature of 1° F., and $\frac{b}{772}$ being the latent heat of expansion of 1 lb. of the substance for 1° rise of temperature.

Practically, this quantity, or the latent heat of expansion, is included in the specific heat, for ordinary solids and liquids, the quantities a and b not being separated. The amount of heat necessary to raise one pound of a solid any number of degrees in temperature is thus c, the specific heat, multiplied by t, the number of degrees, c being the mean specific heat of the solid for the given range of temperature.

A remarkable change occurs, however, in the relative values of A, B, and C, when a body changes its state from solid to liquid, or from liquid to gaseous.

At the melting point, the quantity A vanishes suddenly or gradually, and the addition of heat, after that, does not raise the temperature of the residual mass of solid, or that part which has become liquid, each additional unit of heat being expended in the work designated by B + C; B being the greater, and C being usually very small, and sometimes negative.

This quantity $\frac{B + C}{772}$ for each pound of the substance melted is called the latent heat of fusion, and its value in units of heat for various substances has already been given, p. 717.

After the body has all passed to the liquid state, if heat be still applied, the quantity A reappears, the substance is further heated and the temperature rises, and from the melting point to

the boiling point, the quantity of heat necessary to raise the temperature of the body 1° F. is again composed of the three terms; C being, as in the solid state, very small, since the expansion of liquids is small, and the specific heat of the liquid is taken to represent the combined quantities A, B, and C. The quantity of heat necessary to raise the temperature of 1 lb. of water from the melting point of ice to the boiling point of water being

$$q = c \times 212°,$$

and through any given range of temperature

$$q = c \times (t_1 - t),$$

c being the mean specific heat for the given range of temperature, and $t_1 - t$ the number of degrees.

At the boiling point of a liquid, another remarkable phenomenon occurs, similar to that attending the melting of the body. The term A again vanishes, or in other language, the temperature of the liquid and its vapour remains constant, as long as the external pressure is constant, until all the liquid has passed to the state of vapour. All the heat transferred to the substance during this operation becomes latent, or is expended in producing the work represented by B + C.

The sum of these two quantities expressed in units of heat, or $\frac{B + C}{772}$ is in this case the quantity which has received the name of latent heat of evaporation, and which has been determined by various investigators for different liquids and for different boiling points. Table XIII. gives the latent heats of evaporation, in English units, of various substances, the pressure on the external surface being one atmosphere;—

TABLE XIII.—LATENT HEAT OF VAPORIZATION.

Water	966·23	Regnault.
Ether	164·0	Favre and Silberman.
Oil of turpentine	123·0	" "
Alcohol	372·7	" "
Hydrocarbons	107·8	" "

The change from the state of liquid to the state of vapour being accompanied, at the pressures most employed, by a considerable increase of volume, the term $\frac{C}{772}$ in the general formula $\frac{B}{772} + \frac{C}{772}$, which represents the latent heat of vaporization, becomes appreciable. The term $\frac{B}{772}$ represents the heat employed in overcoming the attractions of the particles, by which they are entirely removed from attractive influence on each other; this constitutes the principal part of the latent heat. While the term $\frac{C}{772}$ represents the work of overcoming the external pressure in units of heat, and may be represented by $\frac{PU}{772}$, P representing the external pressure, and U the increase of volume which the liquid undergoes in expanding to the vaporous form; so that if L represents the total latent heat, we may represent this by

$$L = \frac{B}{772} + \frac{PU}{772};$$

or

$$L = R + PU\frac{1}{772},$$

R representing the units of heat corresponding to $\frac{B}{772}$.

The latent heat of vaporization of water for different temperatures or pressures, to about 375° F., was determined by Regnault, in a series of experiments. Rankine gives the following empirical formula, based on that of Regnault, which represents the results of his experiments;—

$$L = 1091 \cdot 7 - 0 \cdot 695\,(t - 32°) - 0 \cdot 000000103\,(t - 39 \cdot 1°)^2,$$

or, approximately for technical applications,

$$\begin{aligned} L &= 1092 - 0 \cdot 7\,(t - 32°) \\ &= 966 - 0 \cdot 7\,(t - 212°). \end{aligned}$$

From this formula it is apparent that the latent heat of evaporation, for water, diminishes with the temperature above 212°.

The total heat necessary to transform 1 lb. of water, from the liquid condition at the melting point of ice, to the condition of saturated vapour or steam at the temperature t, may now be estimated. This is called the total heat of vaporization, and represents the sum of the heat which is required to heat the water from the temperature 32° to the temperature t, and the heat which disappears as latent heat. By algebraic symbols the sum is evidently expressed as follows;—

$$Q = c\,(t - 32°) + L = q + L,$$

c being the mean specific heat of water between the limits of temperature, and L the latent heat of vaporization at the higher temperature.

The results of Regnault's experiments, already referred to, led him to the discovery, that the total heat of the vapour of water from the temperature of melting ice, increases at a uniform rate as the temperature rises.

Regnault's formula by which this law is expressed is as follows;—

$$Q = 606 \cdot 5 + 0 \cdot 305\, t,$$

Q being the total heat in calories, and t being expressed in Centigrade degrees.

The equivalent English formula is

$$Q = 1091 \cdot 7 + 0 \cdot 305\,(t - 32^\circ).$$

The expression for the total heat of vaporization is

$$Q = q + L,$$

from which we have

$$L = Q - q;$$

that is, the latent heat of vaporization is equal to the total heat, diminished by the quantity of heat necessary to raise the temperature of the liquid, from the melting point of ice to the final temperature of evaporation.

In practice, the specific heat of liquid water may often be regarded as unity, and q for 1 lb. of water will then be represented by $1 \times (t_1 - t)$, or $(t_1 - t)$ the difference of temperatures.

The above formula for the total heat, gives the total heat necessary to raise the temperature of 1 lb. of water from 32° to any temperature, and evaporate it at that temperature. Water is not usually obtained in industrial processes at so low a temperature as 32°, and is often heated, by what would otherwise be waste heat, to a temperature as high as possible, before its introduction to the evaporating vessel.

If from the total heat as given above by the formula

$$Q = 1091 \cdot 7 + 0 \cdot 305\,(t - 32^\circ)$$

we subtract the heat necessary to raise 1 lb. of water from 32° to the temperature of the feed-water t_1, we shall have the total heat required to raise the water from the temperature t_1 to t, and evaporate it at t° F.

$$Q = 1091 \cdot 7 + 0 \cdot 305\,(t - 32) - c\,(t_1 - 32),$$

c being the mean specific heat of water between 32° and t_1, or, approximately, c being 1, the formula may be written—

$$Q = 1092 + \cdot 3\,(t - 32) - (t_1 - 32).$$

In experiments to determine the evaporative powers of given kinds of fuel, or of given boilers, for the purposes of comparison, it is necessary to refer all such experiments to the same standard conditions; and it is usual to select the condition of water supplied to a boiler at 212° F. and evaporated at that temperature; at which the number of units of heat necessary for each pound is 966. If the water is actually supplied at a lower temperature, and evaporated at a higher temperature, the quantity of water which would have been evaporated under the standard conditions of temperature, that is from and at 212°, by the same quantity of fuel burned, may be found by a simple proportion, thus;

Let W_1 be the weight of water actually evaporated at the higher temperature by the total heat Q_1 found by the above formula, and X the quantity which would have been evaporated if the water had been supplied and evaporated at 212°. Then we shall have, evidently,

$$X\,966 = W_1\,Q_1$$

and

$$X = W_1\,\frac{Q_1}{966}.$$

The following formula for the factor $\frac{Q_1}{966}$ for any temperature t_1 of the feed-water and any other temperature t of the evaporating point, is given by Rankine;—

$$F = I + 0 \cdot 3\,\frac{(t - 212^\circ) + (212 - t_1)}{966}.$$

When dry saturated steam is superheated, it is evident, from what precedes, that the additional quantity of heat necessary to raise the temperature of 1 lb. of the steam 1° will depend on the specific heat of steam. This, as determined by Regnault, is 0·475, and to heat saturated steam from the temperature t, its boiling point, under a given pressure, to a temperature t_2 under the same constant pressure, will be $0 \cdot 475\,(t_2 - t)$.

So that the total heat of superheated steam may be found by the formula

$$Q = 1091 \cdot 7 + 0 \cdot 305\,(t - 32) + 0 \cdot 475\,(t_2 - t).$$

The total quantity of heat in English units, necessary to raise the temperature of 1 lb. of water from 32° to a given temperature, and evaporate it at that temperature, has been given in the form $Q = q + z$, from which we have $z = Q - q$, in which q represents the quantity of heat required to raise the temperature of the liquid from 32° to the given temperature, and z the quantity necessary to evaporate it at that temperature, or the latent heat of vaporization. It has been also stated that the quantity z is really composed of two terms, in which R represents that part of the latent heat

which arises from the work of the heat in overcoming completely the molecular attractions, and $\frac{PU}{772}$ that part which arises from the work performed in the expansion of the volume of the liquid to the volume of the liquid and its vapour; the increase of volume being represented by U and the external pressure by P. The total quantity of heat required to raise 1 lb. of water from 32° to any temperature, and evaporate it at that temperature, will then be expressed by

$$Q = q + R + \frac{PU}{772}.$$

In this expression q may be said to be the quantity of heat contained in the water at the temperature of vaporization, R the quantity of heat contained in the vapour, and $\frac{PU}{772}$ a quantity of heat which has been converted into external work.

The separation of the latent heat of vaporization into its two parts, and the determination of the values of these parts, is due to Zeuner, who calls the quantity q the heat of the liquid, the quantity R the internal latent heat, and the quantity $\frac{PU}{772}$ the external latent heat.

If from the total quantity of heat Q, we subtract $\frac{PU}{772}$, we shall have $J = Q - \frac{PU}{772}$, which is designated by Zeuner the heat of the vapour. Its value indicates the excess in units of heat of the heat, contained in unit of weight of the vapour, over the heat contained in the unit of weight of the liquid at 32° F. from which it was produced.

The heat of the vapour J and the internal latent heat $R = L - \frac{PU}{772}$ are independent of the mode of evaporation, while in employing the total heat of vaporization Q, and the latent heat of evaporization L in the ordinary mode, it is necessary to suppose that the evaporation takes place under constant pressure.

The quantities J and R are related to each other according to the last two expressions by the formula

$$q = J - R,$$

because we have from these expressions

$$J - R = Q - L,$$

and from a preceding formula

$$q = Q - L.$$

The quantity $\frac{PU}{772}$ in the preceding formulas might be calculated from the formula of Mariotte and Gay-Lussac: $PU = RT$ for any temperature t, or any absolute temperature T, if vapours were strictly subject to the law of perfect gases; but as this formula cannot be applied, Zeuner employs another, based on the dynamic theory of heat, by which the value of $\frac{PU}{772}$ is found, and in which the values of L are taken from the experiments of Regnault.

The values of this term having been found for different pressures and temperatures, if these be subtracted from L, the results will give the corresponding values of R.

The quantity of heat contained in a mixture of liquid and vapour, whether the liquid be mechanically suspended in the form of minute drops, constituting wet steam, or remain in a mass at the bottom of the vessel, may be found, if the relative quantities can be determined. If X be the weight of vapour in 1 lb. of the mixture, the quantity of heat in the liquid at the temperature of vaporization will evidently be q, and R being the latent internal heat of 1 lb. of vapour, X R will be the latent internal heat of the quantity of vapour X; hence the total heat in the mixture will be

$$Q_1 = q + RX,$$

the quantities q and R being found from the table.

The usual method of determining the total heat of wet steam has been, to regard the total latent heat of the vapour as contained in the steam, and to employ the formula

$$Q_1 = Nq + N_1 L = N(t - 32°) + N_1 [1091{\cdot}7 + 0{\cdot}305\,(t - 32°)],$$

N being the number of lb. of water, and N_1 the number of lb. of vapour in the mixture; the specific heat of water being 1, and the initial temperature being 32°.

The difference between this formula and the last, from which we have

$$(N + N_1)\,Q_1 = (N + N_1)\,(q + RX),$$

being that the internal latent heat of the vapour, only, is considered, $N + N_1$ being the total weight of liquid and vapour.

The values of $Q = q + R + \frac{PU}{772}$ found from tables of the properties of saturated steam, conform to the law of Regnault, that the total heat increases uniformly as the temperature rises.

The amount of this increase is small even for a great range of temperature. For instance, the total heat necessary to raise a pound of water from 32° to 212°, and evaporate it at that temperature, is 1146·6 units of heat; and the quantity necessary to raise the same amount of water from 32° to 329·5° F. corresponding to 7 atmospheres, and evaporate it at that temperature, is only

1182·47, or 35·9 additional units of heat; less than $\frac{1}{33}$ part of the latent heat of evaporation of 1 lb. of water at 212°.

The values of z, the latent heat of evaporation, may be found, for any given pressure or temperature, by adding together the corresponding values of R and $\frac{P\,U}{772}$.

The term density refers to the degree of approximation of the molecules of a body to each other. It becomes specific when it refers to the number of molecules or atoms in a unit of volume of a given substance, this unit being a standard for all bodies. In English measures, 1 cub. ft. is the standard unit of volume, and the weight of 1 cub. ft. of a substance in any condition, is the specific weight of that substance in that condition. It is usual to express specific weights in terms of the weight of a unit of volume of a standard substance, the latter weight being taken as unity. Water is the general standard for specific weights, but for gases and vapours air is also taken as a standard, the weight of 1 cub. ft. of air being unity.

Table XIV. shows the relative densities at 32° F., and one atmosphere pressure, of some of the gases commonly met with:—

TABLE XIV.—RELATIVE DENSITIES OF GASES.

Air	1·00000	Water	1·00000
Nitrogen	0·97137	Air	0·0012932
Hydrogen	0·06926	Nitrogen	0·0012562
Oxygen	1·10563	Hydrogen	0·0000896
Carbonic acid	1·52901	Oxygen	0·0014298
		Carbonic acid	0·0019774

Table XV. gives the weights of 1 cub. ft. of each of the same substances in pounds avoirdupois, under the same conditions, namely, at 32° F. and one atmosphere pressure, except for water, which is taken at 39·1° F.:—

TABLE XV.—WEIGHT IN POUNDS AVOIRDUPOIS OF 1 CUB. FT.

Water	62·425	Oxygen	0·08926
Air	0·08073	Carbonic acid	0·12344
Nitrogen	0·07860	Steam	0·0502
Hydrogen	0·00559		

The density of a perfect gas, at any other pressure and temperature, may be found from the law of Mariotte and Gay-Lussac.

In the expression

$$P\,V = R\,T$$

V may be taken as the volume of unit of weight or specific volume, and if d represent the weight of unit of volume or specific weight, we shall have $V\,D = I$ and $V = \frac{I}{D}$;

hence

$$\frac{P}{D} = R\,T,$$

and for any other pressure and temperature $\frac{P_1}{D_1} = R\,T_1$.

From these two equations we obtain by division

$$\frac{P}{P_1}\;\frac{D_1}{D} = \frac{T}{T_1},$$

and

$$D_1 = D \,.\, \frac{P}{P_1}\;\frac{T}{T_1}.$$

The density here considered, being the specific weight, or weight of a unit of volume, may be found in the above table, headed weight in pounds avoirdupois of 1 cub. ft., for any perfect gas mentioned in the table.

The specific volume of a gas is the volume of unit of weight. In English measures 1 lb. avoirdupois is the unit of weight, and to obtain the specific volume we have $V = \frac{1}{D}$ the reciprocal of the specific weight.

Specific volumes, or volumes of 1 lb. of each of the substances named, are given below in cub. ft., for 32° F. and one atmosphere;—

Air	12·3870	Oxygen	11·2032
Nitrogen	12·7226	Carbonic acid	8·1011
Hydrogen	178·8909	Steam	19·9203

If saturated vapours could be treated as perfect gases, the preceding formulas for determining the specific volumes and specific weights of the vapour of water might be employed, in which, for English measures, P is the pressure in pounds per sq. ft., V the volume of 1 lb.; R is a constant equal to 85·766, and T the absolute temperature. The constant 85·766 is derived from the corre-

sponding value of R for air, on the supposition that the weight of 1 cub. ft. of saturated steam is 0·622 that of air at the same temperature and pressure.

From the above formula we have for saturated steam—

$$PV = 85{\cdot}766 \times T; \qquad V = \frac{85{\cdot}766 \times T}{P}; \qquad D = \frac{1}{V} = \frac{P}{85{\cdot}766 \times T}.$$

Let it be required, for instance, to determine the volume of 1 lb. of saturated steam at a pressure of 6 atmospheres. This pressure corresponds to a temperature F. of 318·6, and the corresponding absolute temperature will be 459·4 + 318·6 = 778° F. Six atmospheres pressure is 12700·8 lb. a square foot, and the formula becomes, for the specific volume,

$$V = \frac{85{\cdot}766 \times 778}{12700{\cdot}8} = 5{\cdot}253 \text{ cub. ft.},$$

and for the specific weight,

$$D = \frac{12700{\cdot}8}{85{\cdot}766 \times 778} = 0{\cdot}1903 \text{ lb.}$$

It has been remarked, however, that for saturated vapours, the law of Mariotte is strictly applicable, only on the supposition that the vapour is in the superheated condition.

In order that this law may be applicable, it is necessary that the specific weight of vapour shall bear a constant ratio to that of air at the same pressure and temperature. This ratio, as determined by Regnault for saturated steam, is 0·622. The following gives the ratios of the weights of unit of volume of the vapour of water, relative to air, for increasing pressures, as determined by Zeuner theoretically;—

	Density of vapour relative to air.		Density of vapour relative to air.
0·1	0·621	2	0·648
0·5	0·633	5	0·662
1	0·640	10	0·676

From this table it will be seen that it is only at very low pressures that the law of Mariotte and Gay-Lussac will apply to saturated vapours. For pressures such as are ordinarily employed in the steam engine the law does not apply.

A knowledge of the specific volumes and specific weights of saturated vapours, especially of the vapour of water, is of great importance, in technical applications, for the pressures and temperatures usually employed, and these have been already treated of in this Dictionary.

Chemical action, when accompanied by the development of light and heat, is usually called combustion. Inflammation denotes that kind of combustion in which the products are gaseous, and flame is produced. Ignition is simply the incandescence of a body unattended by chemical change. The phenomena of heat being those of rapid molecular motions, the heat and light developed by combustion must indicate an increased molecular movement in the particles of bodies, when combustion takes place, proportional to the amount of force of the chemical attractions. The heat of combustion may, therefore, be rationally explained, by saying that intense and violent increase of motion in the particles of the compound is produced by the chemical attractions. Ordinary combustion consists in the combination of oxygen with various substances; the temperature required being different for different substances, and varying for the same substance with the rapidity of the combustion. Phosphorus combines slowly with oxygen at 77° F.; charcoal burns slowly, but does not ignite, below a red heat; sulphur burns in air at about 550° F.

But most elementary substances require to be heated to redness before combustion in oxygen or the air takes place. According to Peclèt, solids emit light, or become dull red, at about 750° F.

Compression of air does not appear to facilitate combustion, unless the combustion takes place rapidly, and is consequently attended with considerable evolution of heat.

Most substances burn with great rapidity when in a finely divided state. Fine dust of many substances burns in this manner with a rapidity, which in a closed space, may give rise to such a degree of pressure from the expansion of the gases, as to produce phenomena like explosions. A single spark may thus produce instantaneous combustion.

Porous substances often absorb and condense air within their pores; oxidation begins, accompanied by an elevation of temperature, which accelerates the oxidation until the process produces spontaneous combustion. Charcoal powder, masses of tow, cotton, or rags, saturated with oil, sawdust mixed with oil, moist hay, and other substances in similar conditions, have thus been known to burst into flame.

Wood does not take fire in oxygen gas, according to Thénard, at temperatures below about 600° F., but if it be long exposed to a high temperature, even lower than this, in air, it may become partially charred, and rendered so inflammable as to favour the conditions of spontaneous combustion. Charcoal from wood made at a temperature of 480° F. takes fire in air when heated to about 650° F.

Ordinary combustion is accompanied usually by incandescence and flame. If a solid burns without flame, the heat evolved at the surface of contact of the air causes an elevation of temperature of the residual solid particles, which gives rise to a glow, or incandescence, the colour and intensity of the light being dependent on the temperature. Dull red indicates the lowest temperature at which light appears, and dazzling white the highest degree of heat; between these extremes the light passes from dull red, or cherry red, to bright red, dull white, then to a yellowish and finally to a bluish white, and a full or dazzling white.

If the combustible is gaseous, the combination with oxygen may be instantaneous, producing by

the violent concussion of the air an explosion; but in order that this may take place, the combustible gas must be mixed uniformly in the proper proportions, and then heated to the burning point. A similar effect takes place when a solid, such as sulphur or charcoal, is mixed with a nitrate or other solid which gives up its oxygen readily. In both cases it is only necessary that the temperature be raised to ignition at one point by friction, percussion, or the contact of a hot body, the action being then propagated instantaneously throughout the whole mass.

When the combustion is gradual, the contact of the combustible gas with oxygen, or the air, takes place usually at the bounding surface of the gas; as, for instance, when a jet of gas issues from an orifice, or when a column of gas rises from the wick of a candle. The inner mass of the combustible gas does not ignite at first, and the ignited surface assumes the form of a hollow cylinder or cone.

The brightness and colour of such a flame depend not only on the degree of temperature, but upon the presence of solid incandescent particles in the flame. These solid particles arise sometimes from the compound produced by the combination, but in ordinary forms of combustion of fuel they are particles of carbon. Hydrogen gas, carbonic oxide, alcohol, and sometimes coal-gas burn thus with a dull flame.

A bright flame is produced by compounds which contain carbon, from which a portion of the carbon becomes separated by the heat produced, the separated particles being first heated to incandescence, and afterwards burned by contact with the air. If the quantity of air supplied is not sufficient, these solid particles may become cooled and form soot. The visible part of smoke is this soot cooled below red heat. Marsh gas, olefiant gas, ether, volatile oils, resins, and fats, when burned give off carbon in this manner, and may form bright flames, or produce, if the separated particles are not all burned, soot, or smoke. A purely gaseous substance does not become luminous at any degree of temperature however high, luminosity being caused by particles of incandescent solids in the gas.

The combustible ingredients of ordinary fuel, and of the liquids and gases usually employed for the generation of heat, are carbon and hydrogen. These substances combine readily with oxygen, the former producing by the combination carbonic acid, or carbonic oxide, and the latter water. The oxygen required is usually supplied by the atmosphere, which contains about one-fifth of its weight of this substance.

As a general rule, all chemical combinations produce heat, while chemical decompositions cause a disappearance of heat. In the combination of two simple isolated elements heat is evolved only, but where the combination is effected through the simultaneous decomposition of compound substances, the heat evolved is the resultant of that which is produced by the combination of the combustible elements, and that which disappears through the decompositions.

In compounds containing oxygen and hydrogen in the proper proportions to form water, the surplus hydrogen only contributes to the development of heat when combustion takes place.

These elements combine to form water in the proportion by weight of one part of hydrogen to eight parts of oxygen, and by volume, one of hydrogen to one-half of oxygen.

Carbon unites with oxygen in two proportions, namely, to form carbonic acid, six parts of carbon to sixteen of oxygen by weight, and to form carbonic oxide, six of carbon to eight of oxygen. Carbonic oxide is a highly combustible gas, taking up when exposed to air or oxygen at the proper temperature eight additional parts, or one equivalent of oxygen to form carbonic acid.

Carbon completely burned thus produces carbonic acid and satisfies the conditions of perfect combustion. Imperfectly burned, the result usually of a deficiency of air, it produces carbonic oxide.

Air is composed of oxygen and nitrogen. Ordinary atmospheric air contains also, mechanically, watery vapour, and carbonic acid in small quantities. Of these elements the oxygen alone is the active agent of combustion.

Pure dry air contains oxygen and nitrogen in the proportion by weight of—

Oxygen	0·236
Nitrogen	0·764
	1·000

and by volume—

Oxygen	0·213
Nitrogen	0·787
	1·000

The weight of a given quantity of air is thus 4·25 times the weight of oxygen it contains, and 1·31 times the weight of nitrogen. The volume of a given quantity of air is 4·69 times the volume of oxygen it contains, and 1·27 times the volume of nitrogen.

1 lb. of carbon, to form carbonic acid, unites with 2·66 lb. of oxygen, the resultant weight being 3·66 lb. of carbonic acid. This requires 11·3 lb. of air, and produces after combustion, 12·3 lb. Since 1 lb. of air occupies at 32° F. and at the ordinary pressure 14·7 lb. a sq. in., 12·39 cub. ft., it follows that 1 lb. of carbon requires for its combustion, approximately, $12 \cdot 39 \times 11 \cdot 3 = 140$ cub. ft. of air.

1 lb. of carbon, to form carbonic oxide, unites with 1·33 lb. of oxygen, making 2·33 lb. of carbonic oxide. This requires 5·65 lb., or about 70 cub. ft., of air at ordinary temperatures and pressures.

1 lb. of hydrogen, to form water, requires 8 lb. of oxygen, the resultant being 9 lb. of water. This requires, when the combustion is in air, 33·97 lb., or 420·0 cub. ft. of air, and the total weight after combustion is 34·97 lb.

1 lb. of light carburetted hydrogen, or marsh gas, to form carbonic acid and water, requires 4 lb. of oxygen, the resultant being 5 lb. of carbonic acid and water, in the proportion of 1 water to 2·44 carbonic acid. For this combustion, 17 lb., or approximately 210·0 cub. ft. of air are required, making 18 lb. of gas and watery vapour after combustion.

For burning 1 lb. of olefiant gas, 3·43 lb. of oxygen are required, making 4·43 lb. of carbonic acid and water; the volume of air required being approximately 170 cub. ft.

The following Table XVI. gives the atomic formulas, the chemical equivalents, the weight of oxygen, and the weight of the products of combustion in oxygen of the substances named;—

TABLE XVI.—ATOMIC FORMULAS, CHEMICAL EQUIVALENTS, AND PRODUCTS OF COMBUSTION.

Name of Combustible.	Atomic Formula.	Chemical Equivalent.	Products of Combustion.	Atomic Formula.	Chemical Equivalent.	Weight of Fixed Oxygen.	Weight of Oxygen a lb. of Combustible.	Weight of Products of Combustion in Oxygen.
Carbon	C	6	Carbonic acid	CO^2	22	16	2·66	3·66
Carbon	C	6	Carbonic oxide	CO	14	8	1·33	2·33
Carb. oxide ..	CO	14	Carbonic acid	CO^2	22	8	0·57	1·57
Hydrogen ..	H	1	Water	HO	9	8	8·00	9·00
Marsh gas ..	C^2H^4	16	Carbonic acid	$2CO^2$	44			
			Water	4HO		64	4·00	5·00
Olefiant gas	C^4H^4	28	Carbonic acid	$4CO^2$	88			
			Water	4HO		96	3·43	4·43

When the combustion takes place in air, the weight of the products of combustion depends on the quantity of air required in each case. Table XVII. gives a recapitulation of the statements already made in general terms for the combustion of 1 lb. of the different substances;—

TABLE XVII.—PRODUCTS OF COMBUSTION OF 1 LB. IN AIR.

Name of Combustible.	Products of Combustion.	Weight of fixed Oxygen in lb.	Weight of the Products of Combustion in Oxygen in lb.	Weight of Air corresponding in lb.	Weight of Products of Combustion in Air in lb.
Carbon	Carbonic acid	2·66	3·66	11·29	12·29
Carbon	Carbonic oxide	1·33	2·33	5·65	6·65
Carbonic oxide	Carbonic acid	0·57	1·57	2·42	3·42
Hydrogen ..	Water	8·00	9·00	33·97	34·97
Marsh gas ..	Carbonic acid and water ..	4·00	5·00	16·99	17·99
Olefiant gas ..	Carbonic acid and water ..	3·43	4·43	14·57	15·57

Most of the substances involved in ordinary combustion are found only in the gaseous state, and at the moment of combination it is supposed that all, even carbon, become gaseous. It is hence convenient, and often necessary, to know the proportions by volume in which combinations take place.

Table XVIII. exhibits the products of combustion of one volume, 1 cub. ft., of each of the combustibles named, and also in exact figures the number of cub. ft. of air necessary to burn 1 lb. of each of the substances to form the products specified;—

TABLE XVIII.—AIR REQUIRED FOR COMBUSTION, AND RESULTS, BY VOLUME.

Name of Combustible.	Composition by Volume of one Volume.	Composition by Volume of Products of Combustion.	Total Volume of Products of Combustion in Air.	Volume of Air required to burn 1 lb. of Combustible in cub. ft.	Volume of Air Corresponding.	Volume of fixed Oxygen.	Volume of the Products of Combustion.
Carbon ..	C	$2(\frac{1}{2}C + O)$	137·50	137·50	9·39	2·0	2
Carbon ..	C	$2(\frac{1}{2}C + \frac{1}{2}O)$	83·28	68·66	4·69	1·0	2
Carb. oxide	$\frac{1}{2}C + \frac{1}{2}O$	$1(\frac{1}{2}C + O)$	36·14	29·80	2·35	0·5	1
Hydrogen	H	$1(H + \frac{1}{2}O)$	509·1	419·7	2·35	0·5	1
Marsh gas	$\frac{1}{2}C + 2H$	$1(\frac{1}{2}C + O)$					
		$2(H + \frac{1}{2}O)$	228·3	206·4	9·39	2·0	3
Olefiant gas	C + 2H	$2(\frac{1}{2}C + O)$					
		$2(H + \frac{1}{2}O)$	188·5	176·6	14·08	3·0	4

The last column shows the total volume of the gaseous products of combustion in air. The numbers in this column are found in the following manner;—For the combustion to form carbonic acid, 2 cub. ft. of oxygen combine with 1 cub. ft. of carbon to form 2 cub. ft. of carbonic acid. The volume of the carbonic acid after the combustion will be the same as the volume of the fixed oxygen, and after the combustion, the volume of the products remains the same as the volume of air required for combustion.

In the combustion of carbon to form carbonic oxide, however, it will be observed that for each cub. ft. of oxygen used, 2 cub. ft. of carbonic oxide are produced. The amount of air necessary to burn 1 lb. of carbon to form carbonic oxide is given in the table 68·66 cub. ft., which contains $\frac{68 \cdot 66}{4 \cdot 694} = 14 \cdot 62$ cub. ft. of oxygen. Each cub. ft. of oxygen with the carbon forms 2 cub. ft. of carbonic oxide; so that if we add 1 cub. ft. for each cub. ft. of oxygen to the amount of air required, 68·66 cub. ft., we shall obtain the total gaseous product, 83·28 cub. ft.

In the combustion of hydrogen the same ratio is observed. In the combustion of marsh gas 1 cub. ft. is to be added for every two cub. ft. of oxygen; and for olefiant gas, 1 cub. ft. for every 3 cub. ft. of oxygen.

These tables are valuable in determining the quantity of gas that is discharged from furnaces, and also in the discussion of problems relating to draught, and the quantity of heat transferred to water in the generation of steam.

In regard to the vapour of water, if it is cooled to the point of condensation, its volume will practically disappear from the volume of products of combustion, causing a considerable reduction of volume in the case of the hydrocarbons, and making the volume of the gaseous products even less than that of the air introduced.

An important consequence of the dynamic law of heat, and one which has been experimentally verified, is, that all chemical changes are accompanied by corresponding changes of heat. Chemical actions and heat are mutually convertible; and although the quantity of heat evolved, or dispersed, in any chemical change, can only be experimentally determined, yet it has been established that the combination of any two bodies, chemically, is attended by the evolution of a quantity of heat equal to that which disappears in their separation.

The quantities of heat evolved or disengaged in chemical combinations are found experimentally by means of calorimeters. These measurers of heat are employed in various forms, and operate, generally, in such a manner as to exhibit the effects of the heat evolved in acting on a given substance, such as the melting of ice or the raising of the temperature of a given quantity of water; the quantities of heat being thus indirectly measured, by being transferred to some body in which these effects can be estimated in units of heat.

Table XIX. gives in English units, the quantities of heat disengaged by the combustion of the bodies named by oxygen;—

TABLE XIX.—HEAT DISENGAGED.

Names of Combustibles.	Heat evolved by the Combustion of 1 lb. of Combustible.	Names of Observers.
Hydrogen	62·000	Favre and Silberman.
Carbon	14·544	"
Graphite	14·035	"
Native sulphur	3·966	"
Carbon to carbonic oxide	4·466	"
Carbonic oxide to Carbonic acid	4·325	"
Marsh gas	23·513	"
Olefiant gas	21·344	"
Turpentine	19·533	"
Alcohol	12·931	"
Ether	16·250	"
Spermaceti	18·616	"
Anthracite (Pennsylvania) ..	14·114 (calculated)	Morin and Tresca.
" (Mayenne)	15·689 "	"
Bituminous coal	14·400 "	"
Lignites	12·240 "	"
Peat	9·000 "	"
Peat, 20 per cent. water	7·200 "	"
Coke	12·600 "	"
Dry wood	7·200 "	"
Wood containing 20 per cent. water	5·600 "	"
Ordinary illuminating gas ..	18·000 "	"
Gas from iron furnaces	1·620 "	"
Petroleum	21·000 "	"

In this manner the heat evolved in the combination of both simple and compound bodies has been determined by many observers, especial authority being given to those of Favre and Silberman. In the changes which compound bodies undergo, it may be stated, as a general law, that the heat which appears or disappears is the resultant of the action of the simple elements, and where a compound consists of combustible elements only, like carbon and hydrogen, the heat disengaged, is the sum of the quantities of heat disengaged by the combustion of the

separately. This law, though not indisputably established, is considered sufficiently exact for all ordinary purposes. The temperature at which bodies combine, although affecting the rapidity or energy of chemical action, does not affect the total quantities of heat involved in the change.

See BOILER. FOUNDING. PYROMETER.

List of Books on Heat.—Tyndall, John, 'Heat a Mode of Motion,' sixth edition, cr. 8vo, London, 1880. Clausius, R., 'The Mechanical Theory of Heat,' translated by W. R. Browne, 8vo, London, 1879. Baynes, Robert E., 'Lessons on Thermodynamics, cr. 8vo, Oxford, 1878. Box, Thomas, 'A Practical Treatise on Heat as applied to the Useful Arts,' second edition, cr. 8vo, London, 1876. Trowbridge, William P., 'Heat as a Source of Power,' 8vo, New York, 1874. McCulloch, R. S., 'Treatise on the Mechanical Theory of Heat, 8vo, New York, 1876. Fourier, Joseph, 'The Analytical Theory of Heat,' translated by A. Freeman, 8vo, Cambridge, 1878. Maxwell, J. Clerk, 'Theory of Heat,' fifth edition, cr. 8vo, London, 1877.

HORSE-POWER (H.P.).

The unit of work consists of one pound weight raised one foot high, without specifying the time in which such work is done; but for purposes of calculation in connection with steam engines, the time occupied in raising one pound one foot high requires to be included, and so the unit for power becomes one pound raised one foot in one minute. But as such an amount is in general inconveniently small for engines of any size, the standard power usually adopted in practical mechanics is that which is called a horse-power.

Engineers of the last generation, with whom human and animal labour was an important consideration as a source of motive power, devoted considerable care to experiments as to the best modes of applying it, and the quantity of power developed. The main result of their deductions was, that in moving machinery the power of a horse was on the average equivalent to raising one pound 33,000 feet in one minute, or raising 33,000 lb. one foot high in a minute, and since that period the figure of 33,000 lb. has been taken as a standard for horse-power, though it is undoubtedly a high one. This standard is generally accepted, and there is no cause why it should not be universally employed, except that it does not fit accurately with the empirical metrical system, so the French horse-power has been made equal to 32,549 lb. raised one foot high in a minute, not apparently because that is any more accurate than the English standard, but because it is a convenient round number expressing 450 kilogrammetres a minute.

Horse-power is commonly associated with three qualifications, namely, indicated horse-power, effective horse-power, and nominal horse-power.

Indicated horse-power is ascertained by a knowledge of the average steam pressure in pounds upon each square inch of a piston. This is then multiplied by the area in square inches to give the total impelling pressure in pounds. This total is multiplied by the velocity of the piston in feet a minute, and finally divided by 33,000 to convert the expression of units of work, pounds raised one foot high in a minute, into the more manageable figures of horse-power.

Thus whatever power is actually produced by steam pressure in a cylinder becomes known, and forms a tolerably accurate standard by which the performance of an engine may be tested.

Average pressure is measured by the steam engine indicator, but when an engine is doing work, and when running empty or driving shafting. By taking indicator diagrams under both circumstances, it can be ascertained how much power has been consumed in driving the engine and shafting, and how much remains to be usefully expended.

The latter amount is called effective horse-power, and its proportion in relation to the whole power varies according to circumstances, but may be taken as about 5 per cent. of the indicated horse-power when not easily ascertainable.

"Nominal horse-power" is purely a commercial name, and has no defined or generally acknowledged meaning. It is a term giving an approximate idea of the diameter of an engine cylinder, which would be much more reasonably expressed in inches. Such as it is, however, the old standard takes a mean pressure of 7 lb. on the square inch, and a piston velocity of 220 feet a minute for low-pressure engines; and, so far as a comparison of the smaller commercial high-pressure engines may be a guide, an amount of 10 circular inches seems generally the average one allowed for each horse-power. This, for example, makes a 10-inch cylinder to be called 10 horse-power, and a 12-inch cylinder 14 horse-power. These figures do not apply for larger sizes, and each engine if well and strongly made will give far higher results than their nominal horse-power implies.

The elements really entering into the number of horse-power which any engine will develop are, the average effective steam pressure, and the velocity of the piston.

Thus one engine may be so well and strongly constructed as to work with very high pressure steam, and give out twice as much power as another of the common type, while both, so far as the diameters of their cylinders are concerned, are called of the same nominal horse-power. This loose term ought properly to be abolished from an exact science such as engineering has now become, and while its earlier signification has passed away, no new meaning has been defined and generally acknowledged.

The indicated horse-power of an engine may be found by the formula

$$\text{H.P.} = \frac{p \times a \times f}{33{,}000};$$

where H.P. is the indicated horse-power; p, average pressure on its piston in pounds a square inch; a, area of piston in square inches; f, feet travelled in a minute.

It is easy to notice, that if for any diameter of cylinder and speed of piston there be obtained an amount, giving the horse-power at an average pressure of 1 lb. a square inch, a table of such amounts will facilitate calculations, as it would be only necessary to ascertain the average pressure from indicated diagrams, and multiply that amount by the unit of horse-power for each pound pressure. Table I., given by Arthur Rigg, in his treatise upon the Steam Engine, has been prepared for this purpose, and it will readily supply any units of horse-power, beyond what are actually given

for any other velocity of piston, by multiplication or division. For example, a piston of 12 in. diameter at 400 ft. a minute gives 1·366 horse-power for every pound average pressure on each square inch, and will give half or double this amount at speeds of 200 or 800 ft. a minute.

Table I.—Indicated Horse-power for each Pound Average Pressure on a Square Inch, with different Diameters and Speeds of Pistons (Rigg).

Diameter of Cylinder.	Speed of piston in feet a minute.									
	240	300	350	400	450	500	550	600	650	750
inches										
4	·091	·114	·133	·152	·171	·19	·209	·228	·247	·285
4½	·115	·144	·168	·192	·216	·24	·264	·288	·312	·36
5	·144	·18	·21	·24	·27	·30	·33	·36	·39	·45
5½	·173	·216	·252	·288	·324	·36	·396	·432	·468	·54
6	·205	·256	·299	·342	·385	·428	·471	·513	·555	·641
6½	·245	·307	·391	·409	·461	·512	·563	·614	·698	·800
7	·279	·348	·408	·466	·524	·583	·641	·699	·756	·874
7½	·321	·401	·468	·534	·602	·669	·735	·802	·869	1·002
8	·365	·456	·532	·608	·685	·761	·837	·912	·989	1·121
8½	·413	·516	·602	·688	·774	·86	·946	1·032	1·118	1·29
9	·462	·577	·674	·770	·866	·963	1·059	1·154	1·251	1·444
9½	·515	·644	·751	·859	·966	1·074	1·181	1·288	1·395	1.610
10	·571	·714	·833	·952	1·071	1·190	1·309	1·428	1·547	1·785
10½	·63	·787	·919	1·050	1·181	1·313	1·444	1·575	1·706	1·969
11	·691	·864	1·008	1·152	1·296	1·44	1·584	1·728	1·872	2·160
11½	·754	·943	1·1	1·257	1·414	1·572	1·729	1·886	2·043	2·357
12	·820	1·025	1·195	1·366	1·540	1·708	1·880	2·050	2·222	2·564
13	·964	1·206	1·407	1·608	1·809	2·01	2·211	2·412	2·613	3·015
14	1·119	1·398	1·631	1·864	2·097	2·331	2·564	2·797	3·029	3·495
15	1·285	1·606	1·873	2·131	2·409	2·677	2·945	3·212	3·479	4·004
16	1·461	1·827	2·131	2·436	2·741	3·045	3·349	3·654	3·958	4·567
17	1·643	2·054	2·396	2·739	3·081	3·424	3·766	4·108	4·450	5·135
18	1·849	2·312	2·697	3·083	3·468	3·854	4·239	4·624	5·009	5·78
19	2·061	2·577	3·006	3·436	3·865	4·295	4·724	5·154	5·583	6·442
20	2·292	2·855	3·331	3·807	4·285	4·759	5·234	5·731	6·186	7·138
21	2·581	3·148	3·672	4·197	4·722	5·247	5·771	6·296	6·820	7·869
22	2·764	3·455	4·031	4·607	5·183	5·759	6·334	6·911	7·486	8·638
23	3·021	3·776	4·405	5·035	5·664	6·294	6·923	7·552	8·181	9·44
24	3·289	4·111	4·797	5·482	6·167	6·853	7·538	8·223	8·908	10·279
25	3·569	4·461	5·105	5·948	6·692	7·436	8·179	8·923	9·566	11·053
26	3·861	4·826	5·630	6·435	7·239	8·044	8·848	9·652	10·456	12·065
27	4·159	5·199	6·066	6·932	7·799	8·666	9·532	10·399	11·265	12·998
28	4·477	5·596	6·529	7·462	8·395	9·328	10·261	11·193	12·125	13·991
29	4·805	6·006	7·007	8·008	9·009	10·01	11·011	12·012	13·013	15·015
30	5·141	6·426	7·497	8·568	9·639	10·71	11·781	12·852	13·923	16·065
31	5·486	6·865	8·001	9·144	10·287	11·43	12·573	13·716	14·866	17·145
32	5·846	7·308	8·526	9·744	10·962	12·18	13·398	14·616	15·834	18·270
33	6·216	7·770	9·065	10·360	11·655	12·959	14·245	15·54	16·835	19·425
34	6·59	8·238	9·611	10·984	12·357	13·73	15·103	16·476	17·849	20·559
35	6·993	8·742	10·199	11·656	13·113	14·57	16·027	17·484	18·941	21·855
36	7·401	9·252	10·794	12·336	13·878	15·42	16·962	18·504	20·046	23·133
37	7·819	9·774	11·403	13·032	14·861	16·29	17·919	19·548	21·177	24·435
38	8·246	10·308	12·026	13·744	15·462	17·18	18·898	20·616	22·334	25·770
39	8·648	10·86	12·67	14·48	16·29	18·1	19·91	21·62	23·53	27·15
40	9·139	11·424	13·328	15·232	17·136	19·04	20·944	22·848	24·752	28·560
41	9·604	12·006	14·007	16·008	18·009	20·00	22·011	24·012	26·013	30·015
42	10·065	12·594	14·693	16·792	18·901	20·99	23·089	25·188	27·287	31·485
43	10·56	13·20	15·4	17·6	19·8	22·0	24·2	26·4	28·6	33·0
44	11·046	13·818	16·121	18·424	20·727	23·03	25·333	27·636	29·939	34·545
45	11·563	14·454	16·863	19·272	21·681	24·09	26·399	28·908	31·817	36·135
46	12·086	15·128	17·626	20·144	22·662	25·18	27·698	30·216	32·754	37·770
47	12·614	15·768	18·396	21·024	23·652	26·28	28·908	31·536	1 4	39·420

Diameter of Cylinder.	SPEED OF PISTON IN FEET A MINUTE.									
	240	300	350	400	450	500	550	600	650	750
inches										
48	12·846	16·446	19·187	21·928	24·669	27·41	30·151	32·152	35·633	41·115
49	12·913	17·142	19·999	22·856	25·713	28·57	31·427	34·284	37·141	42·855
50	14·28	17·85	20·825	23·8	26·775	29·75	32·725	35·7	38·675	44·625
51	14·832	18·54	21·665	24·76	27·855	30·95	34·045	37·08	40·205	46·425
52	15·437	19·296	22·512	25·728	28·944	32·16	35·376	38·592	41·808	48·240
53	16·041	20·052	23·394	26·736	30·078	33·42	36·762	40·104	43·446	50·13
54	16·656	20·82	24·29	27·76	31·23	34·7	38·17	41·64	45·11	52·05
55	17·275	21·594	25·193	28·792	32·391	35·99	39·589	43·188	46·787	53·985
56	17·909	22·386	26·117	29·848	33·579	37·31	41·041	44·772	48·503	55·965
57	18·557	23·196	27·062	30·928	34·794	38·66	42·526	46·392	50·258	57·99
58	19·214	24·018	28·021	32·024	36·027	40·03	44·033	48·036	52·039	60·045
59	19·902	24·852	28·994	33·136	37·278	41·42	45·562	49·704	53·846	62·13
60	20·558	25·698	29·981	34·264	38·547	42·83	47·113	51·396	55·679	64·245

The system of measurement of nominal horse-power was introduced by Watt, and was an average representation of the actual horse-power of an engine at that time when 7 lb. steam was thought high pressure. But 50 lb. is now the average pressure, and very much higher pressures are in common use. The standard of Watt is therefore now quite inappropriate.

The following scheme for the rectification of the standard nominal horse-power of marine engines and boilers described by J. Macfarlane Gray, in the 'Nautical Magazine,' in 1872, may well be studied in connection with this important matter.

The source of the power being the fuel, the rate at which that can be consumed is the first element in making up the power. For many years Gray had been accustomed to compare the steaming power of marine boilers with the total width of furnaces, and found that the tendency is towards this simple ratio, one ton of steam coals a day consumed for one foot of width of furnaces, irrespective of the length of bar. The fire-grate of ocean steamers has, in many cases, been shorted from 6 ft. to 5 ft. with an increase of steam raising power. Higher consumption than one ton a foot of width is quite common, but only where the boilers are originally too small for the duty required of them, and consequently the fires have to be forced, to the detriment of economy.

The next element in the power is the quantity of steam raised in proportion to the weight of fuel burnt. Assuming that the boiler is properly proportioned, and making no allowance for deficiency of heating surface, the weight of steam is the weight of water evaporated, and for this 10 lb. of water evaporated by 1 lb. of steam coal may be taken as the standard of maximum practical efficiency.

The next element is, how far will steam go towards horse-power. At a little above atmospheric pressure, namely, at 18¼ lb. above zero, 35 lb. of steam an hour will give one indicated horse-power if applied without loss, and without back pressure, and without expansion. The number 35 is one already appropriated by engineers for another purpose, and it will therefore be the more easily remembered for this.

At high pressures, less than 35 lb. of steam would give one horse-power indicated. At 70 lb. gross pressure it would require only 32·36 lb. But each of these pounds would contain a little more heat, and would therefore represent a little more fuel. Evaporating from feed at 120°, the heat to be added to make 18 lb. pressure, is 1062 units; and to make 70 lb., 1086 units must be added. This brings us to the conclusion, that the indicated horse-power, at the high pressure, would require 6 per cent. less heat than the other.

But the temperature of the steam at this higher pressure would be 80° in excess of the temperature at the lower pressure. Efficiency of heating surface depends upon the difference between the temperature of the water in the boiler and the temperature of the gaseous products of combustion. The conducting power of the metal is also reduced by increase of temperature, and is nearly inversely as the absolute temperature of the conducting medium. A difference of 80° will therefore make a difference of, say, also 6 per cent. on the amount of heat abstracted from a given weight of fuel.

The extension of this calculation to higher temperatures gives similar results; we may therefore assume, as being practically correct, that the cost in fuel of one horse-power, without expansion and without loss or back pressure, is the same at whatever pressure the steam is produced. Further, we may, without appreciable error, take this cost as equal to the cost of 35 lb. of steam produced at 18¼ lb. pressure, and that this will require $\frac{35}{10} = 3·5$ lb. of fuel.

The next element is the reduction in efficiency caused by the loss of heat in blowing off where surface condensation is not used. As this loss is proportional to the effect of the steam when used expansively, Gray deals with it after that effect has been calculated.

For the effect of expansion, it may be assumed that in every case the steam will expand in the cylinder to atmospheric pressure, taking that as exactly 15 lb. on the square inch. In framing a rule for a standard such as this, we must not introduce any factor which does not exist as a definite fact. Now, the pressure of steam for which the valves are loaded is, at least in passage steamers, a quantity so fixed that it can be made available for this purpose. The degree of expansion will, therefore, be assumed to be expressed numerically by the gross pressure of steam in boiler in atmo-

spheres of 15 lb. Example, 60 lb. steam by gauge is $\frac{60 + 15}{15} = 5$ atmospheres, and the expansion would be taken as five times.

The effect of a given quantity of steam is, by expansion, increased by the following multiplier, $10 - \frac{9}{R^{\frac{1}{3}}}$, where R = ratio of expansion, when the steam is used without adding heat to it or abstracting heat from it. As any addition of heat would be, in general, by steam jacketing, and, therefore, would have to be drawn from the steam itself, we may apply this formula to our purpose as being nearly true, whether there is or is not a steam jacket.

This multiplier contains a radical, and, in this form, is unsuitable for the calculation of a standard nominal horse-power. As a practical approximation to this multiplier, the following simpler rule may be used, applicable only to expansion from two up to eight times;—

From the number 18 subtract the ratio of expansion, multiply by the ratio, divide by 40, and add ·85, or

$$\frac{R\,(18 - R)}{40} + \cdot 85 = \text{Effect of expansion, as a multiplier,} = E.$$

The Table II. shows the degree of approximation attained by this rule;—

TABLE II.—STANDARD NOMINAL HORSE-POWER.

R	$\left(10 - \frac{9}{R^{\frac{1}{3}}}\right)$	$\left(\cdot 85 + R\frac{(18 - R)}{40}\right)$
2	1·667	1·650
3	2·034	1·975
4	2·284	2·250
5	2·474	2·475
6	2·625	2·650
7	2·750	2 775
8	2·856	2·850

For steam above 120 lb. gross the formula $E = 10 - \frac{9}{R^{\frac{1}{3}}}$ can be used.

By introducing more complicated constants, a closer approximation might have been obtained, but to do so would be objectionable.

It is requisite to have this rule in terms of pressure, the expansion being carried to atmospheric pressure = 15 lb.

From 270 deduct the gross pressure, multiply by the gross pressure, divide by 9000, and add ·85. Or, writing P for gross pressure,

$$\frac{P\,(270 - P)}{9000} + \cdot 85 = \text{Effect of expansion, as a multiplier.}$$

But this rule takes, as yet, no notice of loss by back pressure or by radiation, or from the variations in the temperature of the surface of the cylinder. The loss by back pressure should be proportionately less as the pressure P increases. But the other losses will then be proportionately greater. When expansion is carried further than to 15 lb., there will in general be an increased effect produced, the loss by back pressure will be proportionately more, but the external radiation will not be increased. Upon the whole therefore it may be assumed as a convenient approximation, that, including average deficiency in boiler, the total loss of effect will be one-fourth of the evaporating power of the boiler. We have therefore to reduce the efficiency of fuel from 10 lb. of steam to $7\frac{1}{2}$ lb. of steam a pound of coal. Dividing 35 by 7·5, we get $4\frac{2}{3}$ lb. of coal for an indicated horse-power, without expansion and without loss. From the ton of coal a foot of furnace front we will therefore have $\frac{2240}{24 \times 4} = 20$ horse-power a foot of front.

Gray proposes that this become the nominal horse-power of the boiler twenty times the total width of furnaces in feet.

Considering the loss by blowing off, where surface condensation is not used, evaporating from feed-water at temperature 120°, and maintaining the saltness of water in the boiler at twice that of sea-water, the heat required a pound of steam made is—

The latent heat	$1113 - \cdot 7\,t$	in the steam used.
Increase of temperature	$-\ 120 + t$	
,, ,,	$-\ 120 + t$	in the water blown off.
Sum	$873 + 1\cdot 3\,t$	total expenditure.

When t = temperature therefore $\frac{t - 120}{1\cdot 3\,t + 873}$ = expense of blowing off in parts of the total effect of the fuel. Calculating this, we have

At pressure =	1 atmosphere	8	per cent. loss.
,,	2 atmospheres	10	,, ,,
,,	3 ,,	12·5	,, ,,
,,	5 ,,	14·7	,, ,,
,,	8 ,,	16·8	,, ,,

On referring to Table II. for the effect of expansion, it will be found that these numbers are just six times those given for the effect of expansion. In general, all new engines have surface

condensers, and for these there will be no reduction for blowing off. There is, however, always some loss from this, even with surface condensers, but this, and a supposed equal amount by which in practice the blowing off, without surface condensers, will, in practice, exceed the rule given, is included in the one-fourth deducted for losses in general.

We have for the effect of blowing off the salt,

$$S = \frac{100 - 6E}{100}.$$

The only measurement of which we can make any use in the engine is the diameter of the cylinder. The speed of the piston, the degree of expansion, the proportion between cylinders in compound engines, the size of intermediate receiver, the angle of the cranks, are all to some extent elements involved in the expression of the horse-power of the engine ; but these in different engines vary so indefinitely that no standard can be based upon them.

The rule at present adopted for nominal horse-power we have given above, but even this varies in different localities.

Gray proposes as nominal horse-power of engine, ten circular inches of piston area, counting only the low-pressure pistons in compound engines. This corresponds with 300 ft. piston speed, and 14 lb. pressure effective.

As nominal indicated horse-power, add together the nominal horse-power of the boiler and the nominal horse-power of the engine. That is N.I.H.P. $= \frac{D^2}{10} + 20F$, where D^2 is the sum of the squares of the diameters of the cylinders, and where there is surface condensation. When there is not surface condensation the pressure will seldom exceed 30 lb. steam by gauge, and, therefore, neglecting the pressure, N.I.H.P. $= \frac{D^2}{10} + 17\frac{1}{2}F$. where there is jet condensation.

This rule will run to be nearly equal to taking the speed of piston at 300 ft., and the effective pressure at 28 lb. a sq. in. This pressure is high, but 300 is now a low speed, and as the rule is not expected to be the true measure of power, but only an understood and convenient standard of reference, it may be found a suitable one.

In applying the rule for nominal expansion horse-power, it is proposed to alter the value of P, in the proportion that the nominal horse-power of the engine is greater or less than that of the boiler. The reduction for blow off will also be made on the altered P, for convenience in working out the calculation, and also because that by doing so we slightly increase the effect, when the degree of expansion is reduced, and decrease the effect when the degree of expansion is unduly increased. When there is not surface condensation, there is not this compensating element in the rule. But it will generally be found that where surface condensation is used, the engines will be fitted with steam jackets and other adjuncts, which will maintain the efficiency nearly equal to that given by the rule when the engines are larger, and will not be so much required, although still costing nearly as much when the engines are smaller. Therefore, the diminished loss by back pressure is, in a measure, counterbalanced by the greater proportional cost of jacketing and other adjuncts.

The following is a condensed statement of these rules ;—

D^2 = Sum of squares of diameters of cylinders—do not include the high-pressure cylinders of compounds.

F = Sum of widths of furnaces in feet.

$\frac{D^2}{10}$ = Nominal horse-power of engine.

$20F$ = Nominal horse-power of boiler.

$\frac{D^2}{10} + 20F$ = Nominal indicated horse-power with surface condensation.

$\frac{D^2}{10} + 17\frac{1}{2}F$ = Do. do. do. with jet condensation.

To illustrate these rules, take a pair of surface-condensing engines, 72″ cylinders with boilers having 76 ft. total width of furnaces.

$$D^2 = 72 \times 72 \times 2 = 10368.$$

Nominal horse-power of engines =	$\frac{D^2}{10}$	= 1036·8
Nominal horse-power of boilers	= 20 × 76	= 1520
Nominal indicated horse-power		= 2556·8

Again, take two sets of compound engines, low-pressure cylinders 78 inches, boiler having 72 ft. total width of furnaces.

$$D^2 = 78 \times 78 \times 2 = 12168.$$

Nominal horse-power of engines =	$\frac{D^2}{10}$	= 1216·8
Nominal horse-power of boilers	= 20 × 72	= 1440
Nominal indicated horse-power		= 2656·8

These results agree very closely with what is the *average* indicated horse-power in engines corresponding to these dimensions, and satisfy almost every condition essential for a system of nominal horse-power of marine engines. The calculation is simple, the data are fixed quantities generally

known, and the results agree fairly with average practice. Further, the present nominal horse-power can be easily transferred into the above.

If it is desirable to include these, pressure and expansion, as elements in the calculation,

D^2 and F are used as above.

P = Gross pressure on safety valve, including atmosphere = 15 lb.

$$p = \frac{D^2}{200\,F}\,P.$$

E = Effect of expansion as a multiplier, and is the Nominal Steam Coefficient.

$$E = p\,\frac{(270 - p)}{9000} + \cdot 85.$$

S = Proportion of evaporative power of fuel available, after deducting for the blowing of the salt, when there is not a surface condenser.

$$S = \frac{100 - 6\,E}{100}.$$

Nominal expansion horse-power = 20 F E, with surface condensation.

,, ,, ,, = 20 F S E, with jet condenser.

Take the same examples as before, two cylinders 72″; total furnace width = 76 ft.; steam, 40 lb., with surface condensers.

$$P = 40 + 15 = 55.$$

$$p = \frac{D^2}{200\,F}\,P = \frac{72 \times 72 \times 2}{200 \times 76} \times 55 = 37\cdot 5.$$

$$E = p\,\frac{(270 - p)}{9000} \times \cdot 85 = \frac{37\cdot 5\,(270 - 37\cdot 5)}{9000} \times \cdot 85 = 1\cdot 8187.$$

This represents the nominal steam coefficient, and $4\frac{2}{3}$ divided by this will give the nominal consumption an indicated horse-power, namely, $\frac{4\cdot 666}{1\cdot 8187} = 2\cdot 56$ lb. an hour.

Nominal expansion horse-power, or N.E.H.P. = 20 × 76 × 1·8187 = 2764.

And if with jet condensation, it would be this multiplied by S;

$$S = 100 - \frac{(6 \times 1\cdot 8187)}{100} = \cdot 891.$$

N.E.H.P. = 2764 × ·891 = 2463.

Applying this to a compound engine, the same as before, 78 in. cylinders, 72 ft. of furnace width, steam 60 lb.

$$P = 60 + 15 = 75.$$

$$p = \frac{D^2}{200\,F}\,P = \frac{78 \times 78 \times 2}{200 \times 72} \times 75 = 63\cdot 4.$$

$$E = \frac{p\,(270 - p)}{9000} + \cdot 85 = \frac{63\cdot 4\,(270 - 63\cdot 4)}{9000} + \cdot 85 = 2\cdot 30.$$

This is the nominal steam coefficient, and $4\frac{2}{3}$ divided by 2·3 gives 2·024 lb., the nominal consumption an indicated horse-power an hour. Nominal expansion horse-power, or N.E.H.P. = 20 × 72 × 2·3 = 3312.

These results 2764 and 3312 agree very closely with the *maximum* indicated horse-power of engines having these dimensions. These rules do not refer at all to non-condensing engines. When the rule for the others has been finally fixed, it will be easy to make a modification of it applicable to non-condensing engines with a blast draught.

HYDRAULICS.

The application of hydraulic machinery to the various purposes requiring power on board steamships, independently of the propelling power, is a comparatively recent step, and it will be found in many instances to have important advantages over steam power for such purposes. There is a large amount of work, such as loading and discharging cargo, hoisting the anchor and sails, warping the ship into dock, steering, stoking, discharging ashes, for all of which hydraulic power is especially deserving of consideration. The machines, Figs. 1440 to 1457, have been designed by A. B. Brown, of Edinburgh, to meet these requirements.

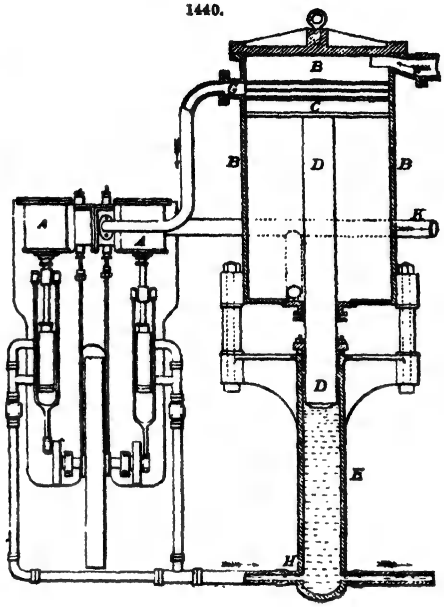
The motive power is supplied by a pair of ordinary double-acting pumping engines, A A, Fig. 1440, which are in connection with a steam accumulator B. This consists of a large steam cylinder 36 in. diameter, fitted with a piston C, and the piston rod D forms the ram of a hydraulic cylinder E, having $\frac{1}{15}$th the area of the steam cylinder B, so that 50 lb. an inch steam pressure gives a water pressure of 750 lb. an inch in the hydraulic cylinder, less the amount of friction. Steam is admitted to the top of the accumulator cylinder at F, from the ordinary donkey boiler or the main boilers; and the pumping engines are supplied by a branch G from the opposite side of the cylinder, and force the water from their pumps into the hydraulic cylinder at H. The bottom of the accumulator cylinder B is open constantly to the exhaust K. When steam is turned on to the accumulator, the engines start, at the same time pumping up the hydraulic ram D, and they continue working until the steam piston rises high enough to close the steam pipe orifice G. The engines then stop; but when water is drawn from the accumulator by the action of the hydraulic machinery, the steam piston descends, maintaining the pressure of 750 lb. an inch upon the water; at the same time by opening the steam pipe G it starts the engines again, and so the accumulator is replenished.

The steam piston of the accumulator is somewhat novel in the mode employed for making the

hemp packing self-tightening. The junk ring is one piece with the piston cover, fitting loosely upon the centre boss of the piston; then if the hemp packing is tight, the inside and outside of the ring are in equilibrium, and there is therefore only a pressure on the annular area of the packing; but if the packing leaks more than the slackness of the small boss of the piston-end can pass, then the equilibrium is disturbed and the junk ring is pressed down and tightens the packing.

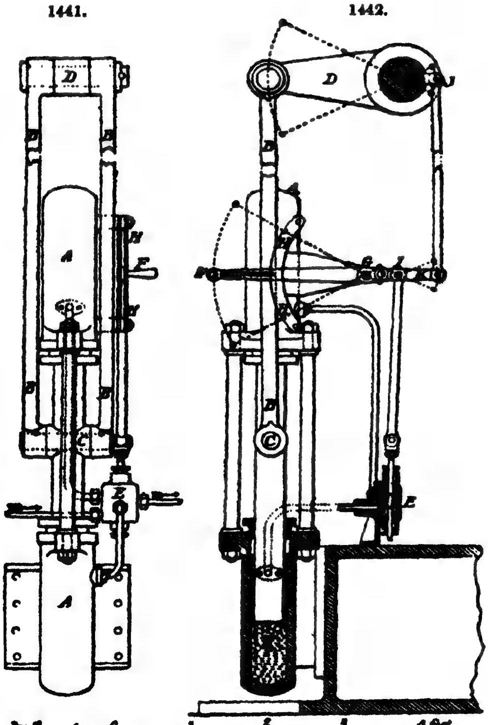
This steam accumulator can be placed either vertically or horizontally, as may be most convenient, and it is usually laid with its engines upon the main engine-room floor. The packing of the accumulator piston and the hydraulic ram, does not require any attention during at least a year's work, and the engines, being automatically stopped and started, require no attention beyond ordinary oiling. Although a water pressure of 700 to 800 lb. an inch is usually maintained for working at full power, the pressure can be reduced to 200 lb. by using a lower steam pressure when doing exceptionally light work.

1440.

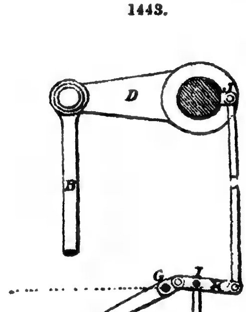


In Figs. 1441 to 1447 is shown the hydraulic reversing gear; it consists of two hydraulic single-acting cylinders A A, having rams 4½ in. diameter and 19 in. stroke, coupled together and working in opposite directions, and connected by side rods B from the boss C to the weigh-shaft lever D. In the working of the apparatus, water from the accumulator is admitted to either of the cylinders as required, by opening the slide-valve E by means of the reversing handle F, which is centred at G, and has a detent rod and quadrant H. The other

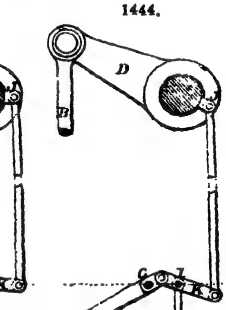
1441. 1442.



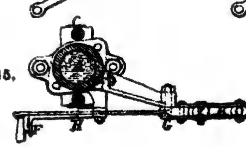
1443.

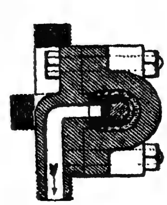


1444.

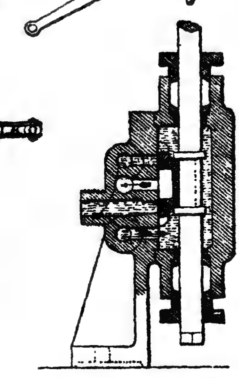


1445.





1446.



1447.

end of the reversing handle F is connected to one end of the short double lever K, the other end of which is moved by a connecting rod from a stud joint J, on the back of the weigh-shaft of the main engines. The slide-valve spindle is attached to the double lever K at an intermediate point I, as in the plan, Fig. 1445.

The effect of this arrangement is that when water is admitted into the lower cylinder by a downward movement of the reversing handle raising the slide-valve, Fig. 1447, the hydraulic rams are then moved in an upward direction, carrying with them the weigh-shaft lever D, Fig. 1444, and reversing the engines accordingly, and by the same movement the stud joint J upon the weigh-shaft is lowered, and closes the valve again, so that the two hydraulic rams are then held fast in whatever position they may be placed. This counteracting cut-off enables the engineer at once, to place the reversing links of the main engines at any degree of expansion, and hold them there, by moving the reversing lever into the desired position in its quadrant, when the rams will follow into that position and stop there.

When it is desired to avoid putting down a pumping engine and steam accumulator, a modification of the above hydraulic reversing gear is used. In this apparatus a double-acting steam cylinder is the moving power, and a similar water cylinder, of one-eighth the area, is coupled to it, for the purpose of controlling its action, and holding the reversing gear locked stationary in any position to which it is shifted, by means of the slide-valve. The water in this cylinder is not under pressure, but simply holds the piston stationary, when the water is prevented from passing from one end of the cylinder to the other, by means of the slide-valve, which closes or opens the communication between the two ends of the water cylinder. This valve is made double, with one slide on each side of the central spindle, so that whichever way the pressure of the water in the locking cylinder acts, when the valve is closed, one or other of the two slides is always pressed tight on its face, and effectually prevents any water from passing. This water valve is coupled to the hollow piston-valve of the steam cylinder, and the two valves are moved together by the reversing lever, which is centred not upon a fixed point, but upon an intermediate lever taking its motion from the weigh-shaft lever of the main engines. The piston rod is connected to the weigh-shaft lever by side rods, and the action of the apparatus is similar to that of the hydraulic reversing gear previously described.

In the hydraulic steering gear, the character of the work to be done in moving the rudder from port to starboard, and the reverse, is much the same as in shifting the links of the main engine from ahead to astern, and therefore the machinery which is effective in the reversing gear suffices also for steering. The only additional provisions in hydraulic steering gear that are not wanted in reversing gear are, that the power applied to the steering gear should increase in proportion to the angle at which the rudder is moved over, that under any excessive strain the machinery should give way, allowing the rudder then to come amidships, but immediately causing it to return when the extra strain is removed, and that whilst the hydraulic steering rams and cylinders are placed aft for direct connection to the rudder, the valve for controlling them should be placed on the bridge, and worked there under the immediate supervision of the officers of the ship.

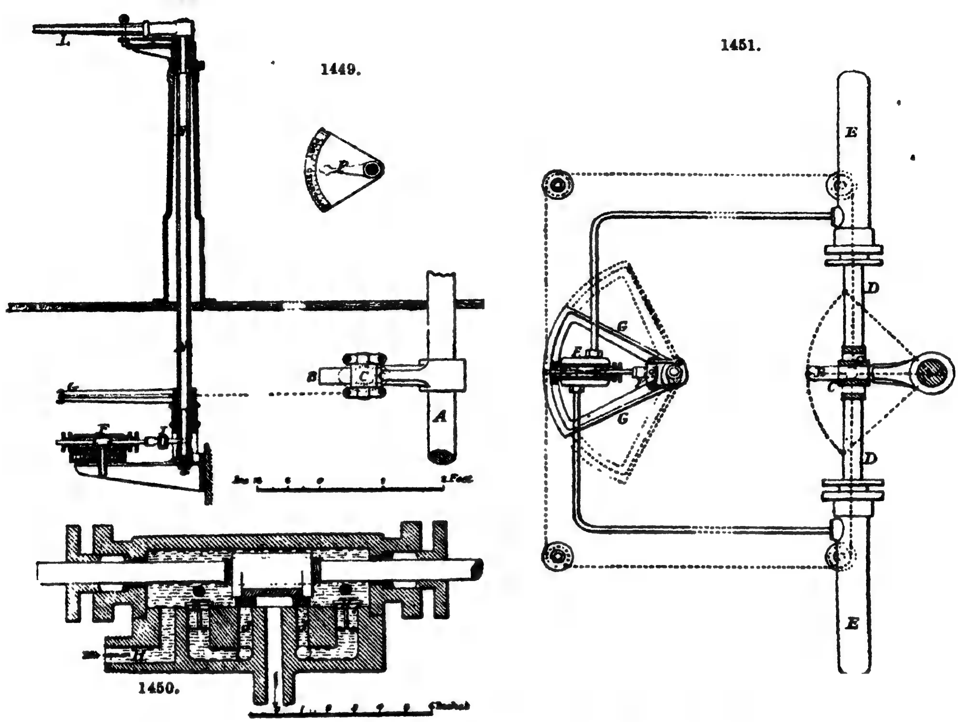
Figs. 1448 to 1450 are of such an arrangement of hydraulic steering gear, connected to the rudder post A by the main tiller B, which is keyed upon it. The end of the tiller is turned cylindrical, to allow the sliding block C to slide radially upon it; and this block is connected by trunnions to the hydraulic rams D D working in the cylinders E E, Fig. 1451, from which separate pipes are carried to the admission ports in the slide-valve F that is placed on the bridge. When the main tiller is moved in either direction towards its extreme position, the sliding block runs out upon it, and the proportionate extent of motion or the effective leverage of the rams is increased, until the power over the rudder becomes doubled, when the rudder is hard over at 45° on either side of the midships position. This is an exceedingly useful property of the steering gear, because in steering with the rudder amidships on long voyages, the quantity of water used is proportionately reduced. A wire cord is carried in each direction from the hydraulic rams to a quadrant G, Fig. 1448, so that any motion taking place in the rudder post communicates a similar motion to the quadrant. The object of this quadrant is to effect an automatic cut-off by the slide-valve F; and also to show by means of an indicator on deck the exact position of the rudder at all times.

The steering valve F is shown in section to a larger scale in Fig. 1450. It is three-ported, the two end ports J J, leading through the pipes to the hydraulic cylinders astern, while the centre port is the exhaust; the water from the accumulator enters the valve chest by the port H. Relief valves K K are provided in connection with each hydraulic steering cylinder, for the purpose of relieving the rudder from any excessive strain, in the event of a heavy sea striking it. These relief valves remain shut, so long as the strain on the rudder and the hydraulic rams is less than that due to the pressure of about 700 lb. an inch, acting on the area of the rams, but the moment any strain on the rudder exceeds this pressure by about 80 lb. an inch, the valves open internally, and allow the water to flow back into the accumulator, driving the accumulator piston up against a steam cushion. In this way, through the rams of the steering gear, the rudder is practically held in position at all times by an elastic pressure of steam.

The self-closing action of the slide-valve is very similar to that in the hydraulic reversing gear. The steering tiller L, Fig. 1448, is fixed upon the shaft N, which passes down from the bridge to the valve F on the main deck, terminating in a crank at the bottom. This crank by a pin and connecting link works one end of a lever I, Fig. 1451, the other end of which is attached by a similar connecting link to a crank pin in the quadrant G; and to the middle of this lever I is jointed the slide-valve spindle. If the valve is opened by moving the steering tiller L and the lever I, water is at once admitted to one of the steering cylinders and exhausted from the other, causing the rams to move the rudder. But as the quadrant G receives motion from the rams by the wire cord, and therefore moves through precisely the same angles as the rudder, its crank pin is carried in the opposite direction to the crank on the shaft N, and the slide-valve is by that means shut again; and any further movement of the steering tiller L will produce further motion in the rams, with a corresponding counteracting motion of the quadrant. The slide-valve is also opened immediately by the quadrant, whenever the rudder is driven amidships by the excessive strain of a heavy sea, and it thus gives a double relief to the water at that moment; but the quadrant closes the valve again on the rudder returning to the position from which it was disturbed. The shaft N of the steering

tiller has a tubular casing, which is fixed to the quadrant below, and is carried up to the top of the steering pedestal, and a pointer P is keyed upon it, which travels over a graduated arc and indicates the position of the rudder, as in the plan, Fig. 1449. In this way any angle at which the steering tiller L is placed, will be followed by a corresponding angular position of the rudder, and this is indicated at once by the small pointer P.

The working of this apparatus is perfectly smooth and noiseless, in consequence principally of the circumstance that no cog wheels are employed. Also the slide-valve required is so small, that



1448. 1449. 1450. 1451.

with a steering tiller of 3 ft. in length, it is found so little power is required to move it that a boy could easily steer.

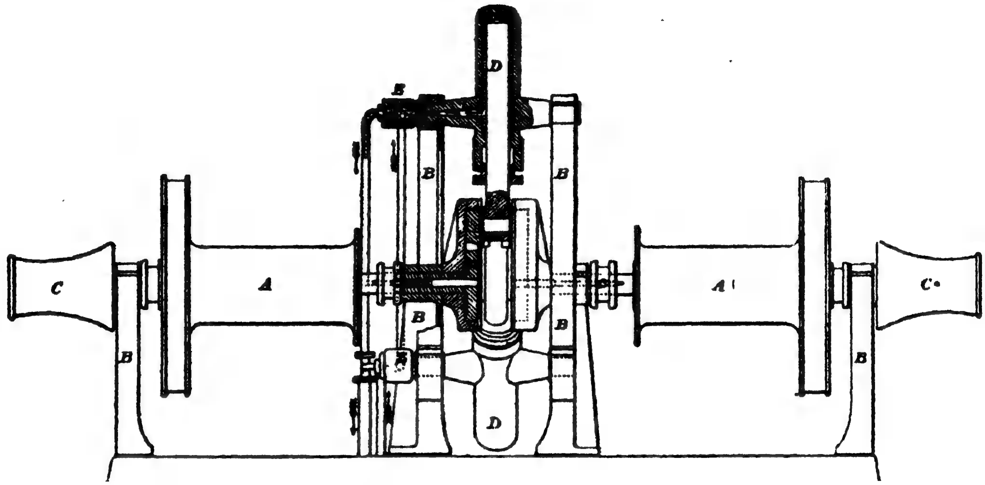
The hydraulic winch is shown in Figs. 1452 to 1456. Two winding barrels A A, with their breaks, are mounted in the frames B B, Fig. 1452, the outer ends of their shafts having warping ends C C keyed on. The winch is driven by the rams, 3½ in. diameter, of three oscillating hydraulic cylinders D, which act upon the same crank pin, Fig. 1453, and they receive and exhaust their water through the trunnions, by means of partially balanced cylindrical slide-valves E, Figs. 1454 to 1456, the casing of which remains stationary, whilst the cylindrical valve or plug E, moves with the oscillation of the cylinder. When this hoist is required to discharge light cargo, such as tea or grain, four ropes can be worked out of one hold, the engines constantly running at 30 revolutions a minute; and with barrels and warping ends of 2 feet diameter a discharging speed of 187 ft. a minute is obtained.

For the purpose of adapting the power of the winch to suit great differences of load, an arrangement is made for readily changing the throw of the crank whilst at work. The crank pin is fixed in two discs F, which are placed eccentrically to the axis of the winch; and each of these discs re[illegible]
sliding [illegible]
discs F, [illegible]
by a lever, and then pushed in again by spiral springs. For the lightest load the hydraulic engine is set at 6 in. stroke; and when the full 2 ton load is to be raised, the sliding bolts are withdrawn, and the eccentric discs allowed to revolve, into the position giving the greatest throw of the crank pin, and the bolts are then allowed to drop into the holes. The engine is then at a stroke of 18 in., and there are three other intermediate positions of 9 to 12 and 15 in. stroke for proportionate loads. In this way the quantity of water used is made to approximate to the work done; and as the stroke can be altered whilst the engine is running, no time is lost.

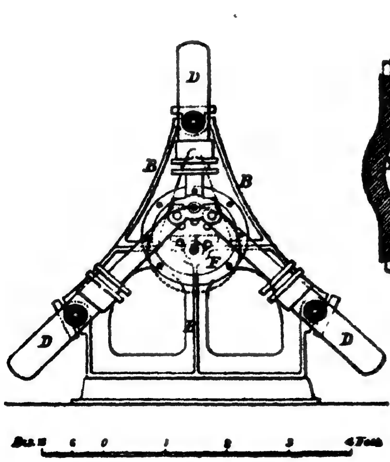
When raising the heavy loads, the engine does not exceed a speed of 20 revolutions a minute, which does not involve any material wear and tear. Gearing is entirely dispensed with in this hydraulic winch, in consequence of the high pressure of water used, which gives a moving force of 3 tons upon each of the three rams acting on a crank of 9 in. radius; and this affords sufficient driving power when attached directly to the winding barrel. Also the entire absence of the noise and vibration, so usual where gearing and quick-running steam engines are employed, is not the least of the advantages in the hydraulic winch.

In connection with either of these hoists, an arrangement is used for swinging the jibs that are suspended from the mast for putting cargo over the side of a vessel. A pair of small hydraulic cylinders and rams A, Fig. 1457, are attached one on each side of the mast B on deck, each ram carrying a pulley C, round which a chain is passed, and its end fastened to the cylinder, with provision

1452.

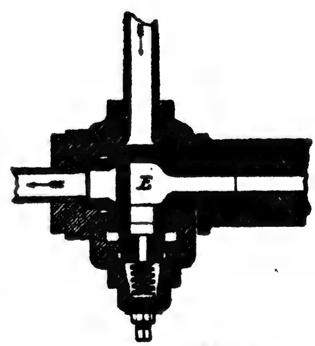


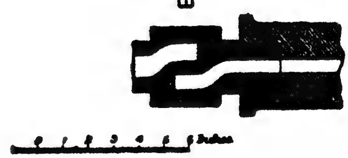
for tightening at D. This chain passes round and is fixed to a pulley E, upon the base of the swinging jib F, and serves to move the jib round by the action of either cylinder alternately. The slide-valve G admits water to either cylinder, and is moved by a lever H, which is centred at the bottom of the joint pin of the jib. The valve is thus opened by the attendant moving the lever to any position in its quadrant, while the actual swinging of the jib shuts it again, in the same



1454.

1455.





1456.

manner as in the valve gear of the reversing or steering apparatus. By having adjustable stops in the quadrant, the jib can always be swung by power exactly plumb over the centre of the hold of any craft alongside.

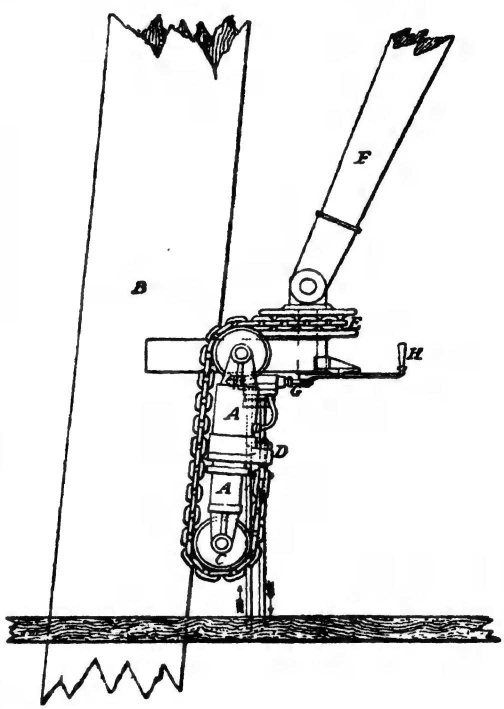
In all the above plans of hydraulic machinery, the pumping engines, steam accumulator, and tank are all placed in the engine room. The tank is charged with water mixed with methylated spirit, to the strength sufficient for resisting frost; or other fluids are employed, of which there are several suitable for the purpose. The fluid is led along a pressure main from the winch furthest aft to the hydraulic engine on the capstan, with branches and stop-valves connecting the different hydraulic machines; and it is returned again by an exhaust main into the tank, which is closed water-tight to prevent evaporation, one charge of fluid being thus worked continuously. The

pressure mains are of wrought iron, put together with right-and-left-handed screwed coupling boxes; one pipe is coned and the other faced flat at the end, so that the joint is drawn together, metal and metal, without any packing.

The hydraulic reversing gear is attached to the main engine frame, with the reversing handle at a convenient height from the starting platform. The hydraulic steering cylinders are placed aft, and connected by wrought-iron pipes with the slide-valve; and the steering tiller is placed amidships, or on the bridge. The hydraulic winches are usually placed on the main deck: and in the reciprocating hoist, the hydraulic rams work through the spar deck.

The advantages of this system of hydraulic machinery on board ship may be stated as follows;—The motive power is placed in the main engine room, is automatically started and stopped, and is kept under the care of a skilled attendant. No steam pipes are carried beyond the main engine room; thus avoiding the heating of decks, and leaking joints from steam pipes carried along the ship, and blowing-through of condensed water from steam winches on deck. A comparatively great speed is obtained in the performance of the various work of discharging cargo, steering, reversing, and the like, and this speed is obtained without any gearing, and without the attendant noise and vibration, and consequently with little wear and tear of machinery.

1457.



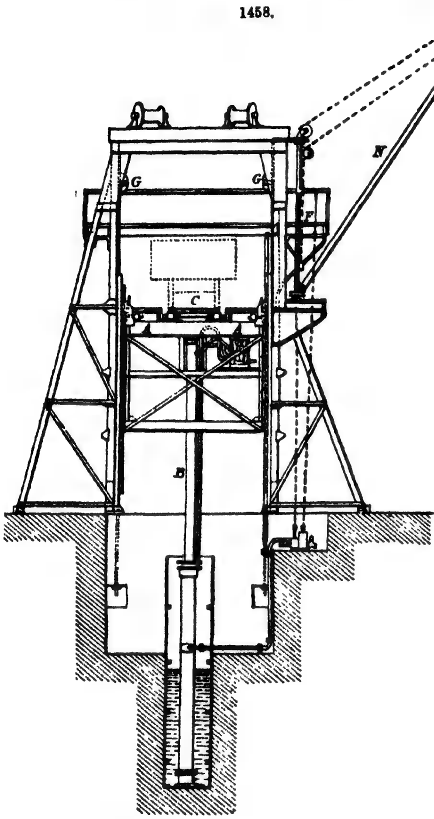
Figs. 1458 to 1467 illustrate several hydraulic machines erected at the Bute Docks, Cardiff, under the superintendence of J. McConnochie. The first hydraulic tips for raising coal waggons from the level, to a height sufficient for discharging them into ships, were erected at the Bute Docks in 1858 with timber framing; but the later ones are entirely of iron, Figs. 1458 to 1461, and are of improved contion. The cradle A that carries the waggon is raised by a vertical hydraulic ram B, of 12 in. diameter and 20 ft. stroke, and slides in guides at the four corners; upon it the loaded waggon is raised to the level of the shoot E, Fig. 1459. The centre portion C of the cradle, with the rails upon which the waggon rests, forms a tipping frame, being pivoted at the front of the cradle; and is tipped with the waggon upon it, as dotted in Fig. 1459 and full in Fig. 1460, by means of a second hydraulic cylinder D, below the cradle and attached to it. This cylinder oscillates on trunnions to follow the motion of the tipping frame, receiving its supply of water through one of the trunnions, from the hollow ram B of the main centre cylinder. The whole working is conveniently managed by a man standing on a side platform F, Fig. 1459, at the top of the framing, with the several hydraulic levers close at hand.

The raising and lowering of the shoot E, Figs. 1459 and 1460, for adjusting its height and inclination, are effected by self-acting means, which entirely dispenses with the hand labour required in balance tips, and obviates the consequent loss of time. Two short arms are made to project from the front of the cradle A, one on each side, under the butt end of the shoot; and when the cradle rises, the shoot is by this means carried up with it to any desired level, and is held there by a weighted pawl, falling into a vertical rack fixed upon the frame on each side of the shoot; or by holding these pawls disengaged from the racks, the shoot can be lowered with the cradle to any lower level. The shoot is secured in addition by a safety chain on each side, which is fixed in the new position by a clip G, Fig. 1458. The two arms that lift the shoot are balanced so as to hang vertically, and clear of the shoot, when not in use; and when required they are thrown into action by pulling a small chain. The point of the shoot is raised or lowered in a similar manner, by means of two chains carried over pulleys at the top of the framing, and brought down the centre of the framing, one at each side, where they are secured to the frame by clips at the desired level. When required to be altered, these chains are put upon strong hooks fixed at the edge of the cradle, and then by lowering or raising the cradle, the point of the shoot is raised or lowered as desired, and the chains are pinned again in the new position by the clips.

As the South Wales coal is of a brittle character, it is found necessary to take special precautions for reducing the loss by breakage, that occurs in discharging the coal waggons into the ships' holds; and for this purpose the anti-breakage crane N, Figs. 1458 and 1459, has been applied with great success, and is now in general use. This has a square iron bucket P holding one ton of coal, made hopper-shaped, with a hinged flap for discharging at the bottom; it is suspended from an independent light jib crane N, fixed at one side of the tip frame, and having hydraulic lifting and turning motions. In commencing the loading of a ship, this bucket is filled

from the shoot, and then lowered to the bottom of the hold, and emptied by pulling up the bolt that secures the flap-door; the process being repeated until a conical heap of coal is formed, high enough to reach nearly to the hatchway. The shoot is then allowed to discharge freely, and delivers close down upon the heap, so as to prevent any breakage of the coal by a vertical drop. The point of the shoot is contracted, to check the fall of the coal down the incline, so that the

1458.



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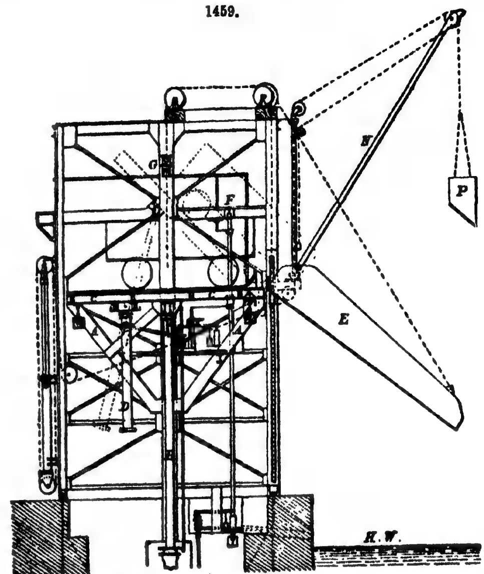
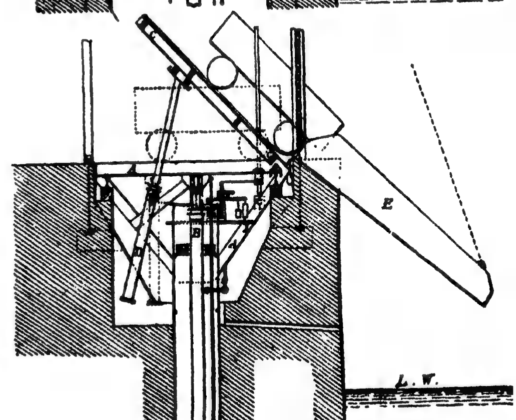




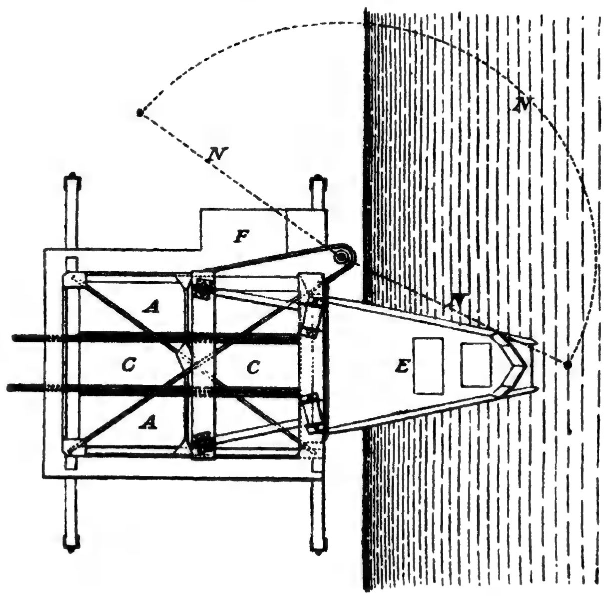
1460.

shoot is choked up by coal, and the discharge from the point requires a little assistance by hand, and is thus kept under control whilst the bucket is being filled. The whole process is effected with great expedition, the discharge of the bucket in the ship's hold being made self-acting, by the bolt that releases the flap-door being fastened to a chain, which is fixed on deck and shortened to the required length as the filling proceeds. These cranes are also used with advantage for discharging ballast or ordinary merchandise, and for filling into waggons the small coal that passes through the screens in the shoots on to the ship's deck.

The hydraulic hauling engine, Figs. 1462 to 1465, has been introduced for the purpose of drawing the waggons on and off the coal tips, in place of horse power, and for turning them on the turntables. It is designed and constructed by Armstrong and Co., and consists of a hydraulic engine with a pair of double-acting oscillating cylinders A A, working right-angled cranks upon a shaft, to which a cupped chain-wheel B can be coupled by a clutch C. The chain by which the waggons are hauled passes over this wheel, into the groove of which it is pressed by a pair of guide rollers D D; and the fall of the chain is piled down upon the floor of the pit E. The entire engine, with the chain wheel and guide rollers, is fixed on the under side of a cast-iron bed plate F, which is flush with the ground when the machine is in use; but it is mounted on trunnions G G, so that it can be turned up when required for examination or repair, as shown in Fig. 1465. By this arrangement the size of the pit required for containing the machine, and the cost of foundations, are much reduced. The pressure water is supplied to the engine at one of the bed-plate trunnions, and the exhaust water conveyed away from the other. The valve for the admission and exhaust of the water to each oscillating cylinder, is placed in one of the trunnions of the cylinder, and is worked by the oscillation; the valves are arranged so that they can be readily removed for examination or repair. The machine is worked by a single hand-

lever H, which throws the clutch C of the chain wheel into gear, and at the same time turns on the water pressure to the cylinders by opening the stop-valve K, Fig. 1465; the lever is held back by a catch in the bed plate when out of action, and the chain wheel is then free to turn upon the shaft and the chain can be drawn out. For starting the machine, the lever is released from the catch, and is then pressed home by a spring J, Fig. 1464; but it is controlled by hand by the attendant so as to start the machine gradually, without any sudden snatch upon the hauling chain. This hauling engine has proved very satisfactory and efficient in working.

1461.



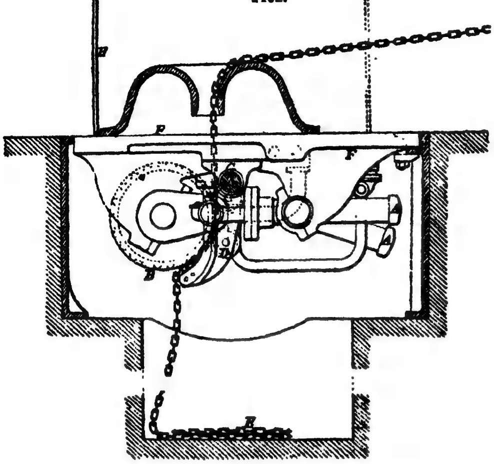
For expeditiously discharging or loading ships with grain or general cargoes, a separate crane for each hatchway is very desirable; but owing to the varying distances between hatchways in different vessels, fixed cranes cannot be adapted to the circumstances; and it occurred to J. McConnochie to meet this difficulty, and still utilize hydraulic power, by employing portable cranes that could be placed in any required position alongside the ships. Figs. 1466 to 1468 are of a portable hydraulic crane, that can be traversed upon a line of railway parallel to the dock wall, and is supplied with water pressure by means of a series of hydrants, placed 20 ft. apart along the dock wall, so that by jointed wrought-iron pipes and a union joint, the power can be supplied to the cranes within 10 ft. distance, in any position. The details were worked out and the crane constructed by Armstrong and Co.; it is similar in construction to the hydraulic cranes in general use, the lifting cylinder and tackle being placed within the wrought-iron pillar A of the crane, which revolves in the centre of a platform D, that is mounted on four carrying wheels travelling on the line of railway. When the crane is in use, the platform is steadied by a screwed resting block B at each corner, and is held down to the rails by clamps C; a cast-iron counterweight E is fixed to the back of the pillar A, to counterbalance partially the load lifted by the crane, and reduce the strain upon the clamps. The turning machinery is fixed on the platform D, which is headed in with wood, and a house is formed at one end for the man working the crane. Two of these cranes, each to lift 46 cwt., and a smaller one to lift 27 cwt., are in use at the Bute Docks, and they have proved very serviceable and satisfactory in work, and are very efficient in discharging a ship quickly, by working at both hatchways at the same time.

The motive power for working the hydraulic machinery at the Bute Docks consists of two pairs of engines with cylinders 16 in. diameter and 20 in. stroke, working direct four force-pumps 4⅝ in. diameter, which supply three accumulators; two of these are placed contiguous to the engine house, and are weighted with 70 tons of gravel suspended on rams 17 in. diameter, giving a pressure of 700 lb. a square in.; the third is placed at a distance of three-quarters of a mile, and is weighted with 100 tons of gravel suspended on a ram 20 in. diameter, giving the same pressure of water. The engines are supplied by four boilers, 25 ft. long and 5 ft. 6 in. diameter, three of which are always kept at work, while the fourth can be used in case of accident or when the others require cleaning. Each pair of engines is capable of working up to 40 horse-power with a boiler pressure of 60 lb. a square in. The pressure pipes in connection with the various machines, extend upwards of three miles, and vary from 3 in. to 5 in. diameter along the mains.

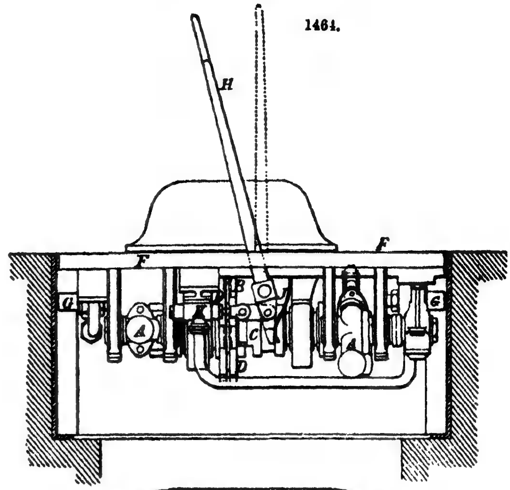
Until late years hydraulic power was used only for very slow direct action; and in packing presses for goods, the motion was so slow as hardly to be perceptible to the eye, requiring ten to twelve minutes to raise the ram of the press 3½ to 4½ ft., which can now be accomplished in less than half a minute. When Robert Wilson proposed to apply direct-acting hydraulic power to the presses used for packing cotton in India, it was considered quite unsuitable for presses with a rise of ram

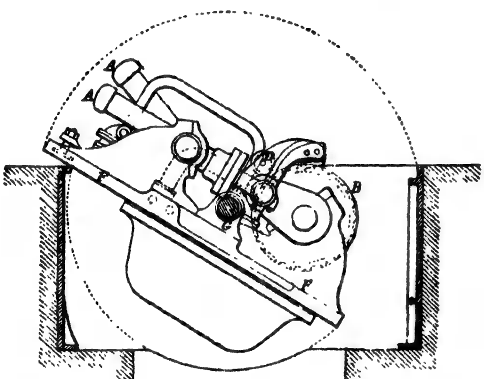
of 12 ft., as it was generally thought that this rise could not be obtained in less than fifteen to twenty minutes, which would only allow of three bales at most being turned out an hour, giving no advantage over the hand-presses at that time generally used in the cotton districts in India.

1462.



1464.





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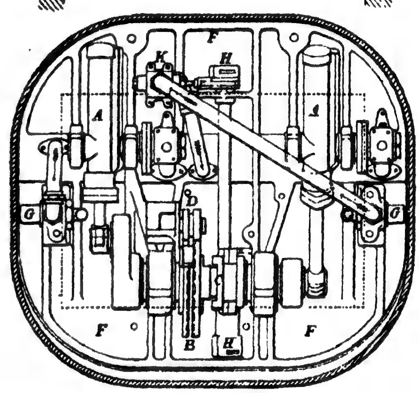
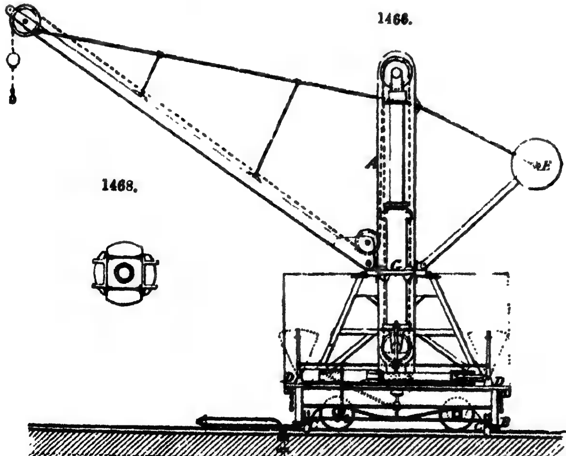


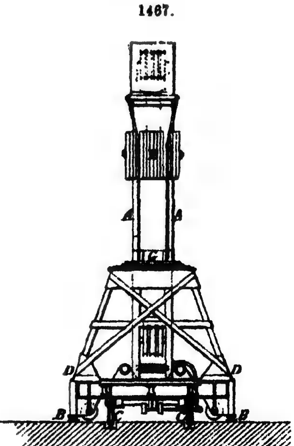
1465.

1466.



1468.

1467.



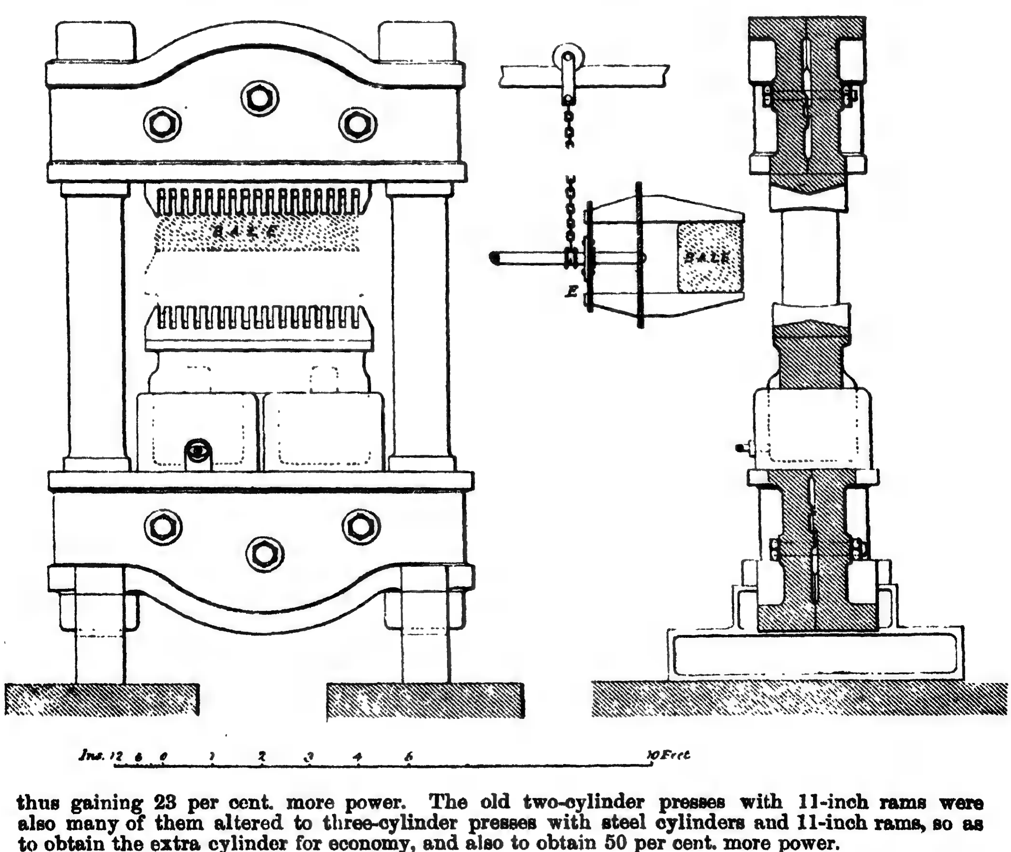
The press Wilson adopted was made and sent out to India in 1857. Its weight is about 30 tons, and it is fitted with two 11-inch rams, and a cotton box 13½ ft. long by 16 in. broad, having a

rise of ram of 12 ft., and capable of compressing 3½ cwt. of cotton into 8 cub. ft. in the press, with a pressure of 500 tons upon the bale. The report received of the working of this press was most satisfactory, stating that twelve bales could be turned out an hour, and that the press could be run up in little more than one minute. This result was obtained through the medium of the horizontal direct-acting high and low-pressure pumping engines constructed in pairs, similar to those already illustrated at p. 1416 of this Dictionary, with cylinders 20 in. in diameter and 24 in. stroke, each pair working four direct-acting pumps, the low-pressure engines pumping water up to a pressure of 1680 lb. or ¾ ton a sq. in., and the high-pressure ones up to a pressure of 3 tons a sq. in.; this difference was brought about by making the pump rams of the low-pressure engines four times the area of those of the high-pressure. The mode of working was as follows;—in starting the press, the resistance of the cotton being then slight, both high and low-pressure engines were set to work, so as to run up the press as quickly as possible; when the resistance of the cotton counterbalanced the low-pressure engines, these stopped of their own accord, and the high-pressure engines finished the bale.

Another press was afterwards constructed with three 9-inch rams, and of similar size and power to the first hydraulic presses. The object of this second plan was to obtain with only one pair of engines a result similar to that previously got with the two pairs and thereby to save the expenses of one entire pair of engines, namely the low-pressure pair, for every four presses. The method of working the three-cylinder press is as follows;—the water from the pumps is admitted at first into the centre cylinder only, thus raising the follower together with the two outside rams which are attached to it, the two outside cylinders, as their rams rise, being supplied with water by gravity from the supply tank, to fill up the space left by the rising rams. When the resistance balances the pressure of the centre ram, the water from the pumps is admitted to the two outside cylinders, thus exerting the pressure of the three rams to finish the bale.

These presses were made much larger and stronger than formerly, and weighed 40 tons each, the cotton box being increased in height to 14½ ft. or even 15 ft. The introduction of steel cylinders led to the alteration of many of the old three-cylinder presses with 9-inch rams, the 9-inch cylinders and rams being replaced with 10-inch steel cylinders and rams to correspond,

1469. 1470. 1471.



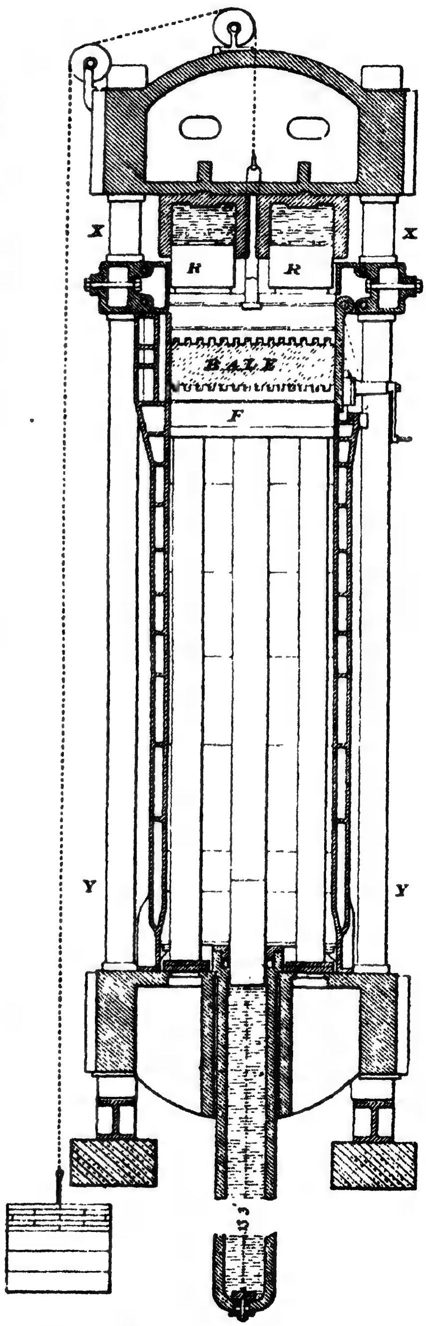
thus gaining 23 per cent. more power. The old two-cylinder presses with 11-inch rams were also many of them altered to three-cylinder presses with steel cylinders and 11-inch rams, so as to obtain the extra cylinder for economy, and also to obtain 50 per cent. more power.

Greater power may also be obtained by means of an auxiliary press or finisher, Figs. 1469 to 1471, of great power, but only of short range. This press, fitted with two 21-inch rams, and capable of exerting a pressure of above 2000 tons, is worked in conjunction with the old presses, in which the

bale is half packed and then transferred by means of an extractor E, Fig. 1470, to the finisher, where the final compression takes place. Bales made in this manner however are hardly satisfactory, as the shape is not so square as when finished in one press, and consequently the measurement is not so good.

To obviate this objection the compound press, Figs. 1472 to 1474, has been designed, by which the bale can be finished to the size required, without being removed from the press. Fig. 1472 is a vertical section, Fig. 1473 a section at X X, and Fig. 1474 at Y Y. The preliminary pressure is given to the cotton through a ram of 11 in. diameter, which forces the bottom follower F upwards to within 5 or 6 in. of the size of bale required. The bottom follower carries with it, whilst rising, two side pillars or supports, which are locked as soon as it reaches the top of its stroke; these along with the 11-inch ram take the strain of the two 19-inch rams R R, which now finish the bale from the top, working downwards, and exerting a pressure upon it of 1700 tons. The bale produced by this press, although not subjected to as great a pressure as when made by the auxiliary finisher, measures equally small in consequence of its better shape.

1472.



The presses in India have had, on account of their height, to be placed in two-storied buildings, which were a great expense, especially up country. To obviate this, a horizontal press has been designed by R. Wilson, based upon the result of numerous experiments, from which it has been found that the pressure required to compress cotton, jute, and the like, into half their natural bulk, is very slight, being only about 3 to 4 lb. a sq. in. of surface exposed to the pressure. The horizontal press, of which Fig. 1475 is a longitudinal section, Fig. 1476 a half plan, and Figs. 1477, 1478, sections on X X and Y Y respectively of Fig. 1476, is fitted with three rams, the centre one C being 9 in. diameter and the two outside ones R R each 14 in. diameter. The box B, in which the cotton or other fibre is placed, is reduced to half the ordinary length, and increased to double the depth. A plate P descending by its own weight compresses the fibre in the box into half its original bulk, and having done so, forms the upper side of the box, and is secured in its place by locking bolts L. Horizontal compression is then given endways, first by the centre one of the three rams, until the resistance counterbalances it, after which the compression is given by all three rams. The bale when finished drops through a trap-door D at the bottom of the box upon a truck, and is removed along a tram or roadway. This press weighs 47 tons, and is capable of exerting a pressure of 1100 tons.

Naturally, as the presses increased in size the engines for supplying them with water were increased likewise; but they were of a similar type to those first employed, until the introduction of the compound press, when a very great improvement was effected by Wilson, by increasing the number of direct-acting pumps from four, that is, one at each end of the piston rods of the pair of engines, to twelve, the effective number in operation at any time being reduced as required to overcome the increase of resistance in the press. The twelve pumps are all the same size as the four formerly used, and are worked as follows. At the commencement of the operations, the pressure being slight, all twelve pumps are set to work until the resistance becomes too great, when one set of four pumps is relieved, by opening a valve at the distribution box of the press, which allows the water to flow, without pressure, back into the tank from which it was drawn. The pumps now deliver less water at a higher pressure, until the resistance of the fibres in the press again counterbalances the power of the pumps; four more of the pumps are now relieved, and the engine with its remaining four pumps and full pressure of water finishes the bale.

The most usual method of forcing water into the cylinders of cotton and other presses is by

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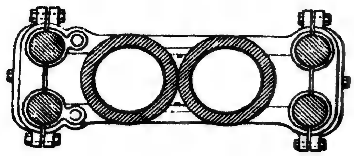
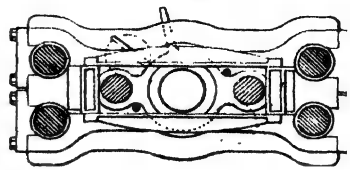
means of force pumps of, comparatively speaking, small stroke and diameter of plunger, driven by gearing and run at a considerable number of strokes a minute. Under these circumstances, unless a great number of pumps are used, the rate of travel of the press ram is extremely slow, notwithstanding that the number of strokes of the pump plungers is comparatively great; and thus for every single stroke of the press there are often some hundreds of beats of the pump valves on

1473.

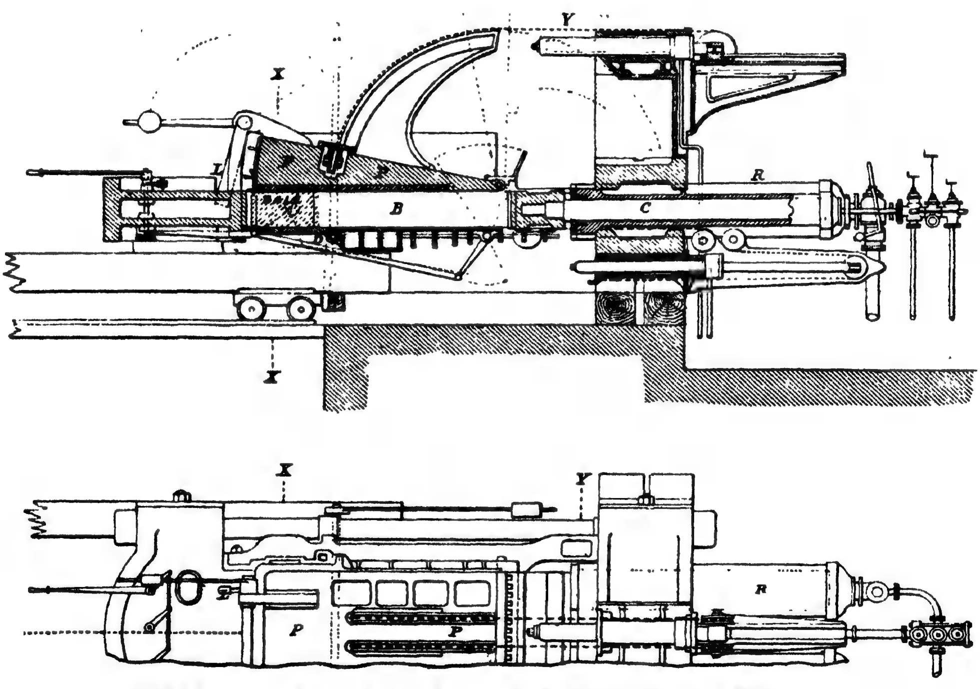


1474.



their seats, and in consequence a difficulty in keeping them tight; in some of the best examples the number of beats is 1000 to 1200 a bale pressed. With this system there is much loss of useful effect from friction of parts; and, while a considerable cost in maintenance is involved, owing to the wear and tear of the gearing, only a very slow speed in working the presses is obtained.

1475.



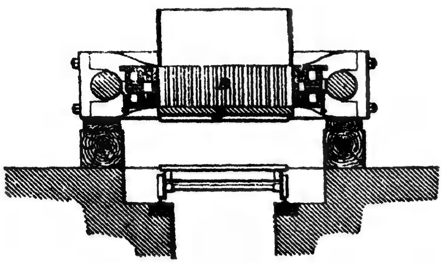
The desirability of substituting some more direct mode of action, with a consequent reduction in the number of working parts in motion, has been for some time recognized. Many attempts have been made to overcome the defects above alluded to. Some engineers have used accumulators, adding sometimes an intensifying arrangement, so that the pump valves are never subjected to the higher pressures; others, by using direct-acting engines with pumps of a larger size, avoid the great wear and tear already referred to, as a necessary consequence of the use of small reciprocating geared pumps; others again have used steam power direct upon the presses for a portion of the stroke, and hydraulic power at the finish.

The direct-acting steam and hydraulic arrangement, described by R. H. Tweddle before the Institute of Mechanical Engineers in 1878, overcomes the objections referred to, and in addition ensures further economy in speed and cost of working.

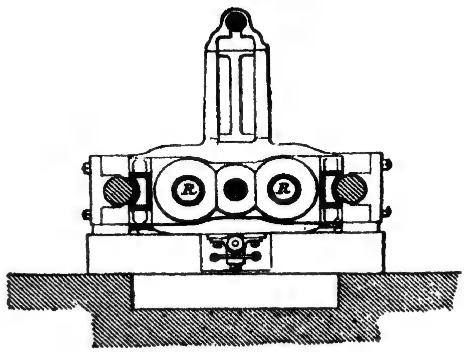
Fig. 1479 illustrates the action of the pressure-intensifying apparatus in connection with an ordinary hydraulic press. The working stroke of the press itself, which is not shown, may be

divided for the sake of illustration into six equal parts. It is assumed that the most intense pressure is required during the last one-sixth part. A and B are two steam cylinders fitted with pistons E and F, and having at their front ends the hydraulic cylinders C and D, in which work plungers G and H; the steam cylinders are of equal size, but the plungers G and H are of different area, their respective areas, as shown in the figure, being in the proportion of

1477.



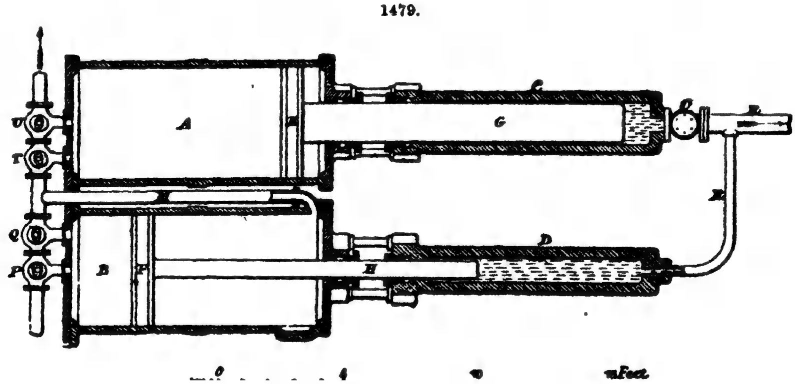
1478.



5 to 1; and the combined cubic capacity of those plungers is assumed to be at least equal to that required for a full stroke of the press ram, a certain margin being added to make up for leakage. It is clear therefore that the lifting ram of the press worked by this pumping apparatus will rise five-sixths of its lift with one stroke of the plunger G, and that one stroke of the plunger H will complete the remaining one-sixth. The sizes of the steam pistons E and F being equal, if the pressure of steam be the same on both, the pressure per sq. in. on the water in the press will be five times greater when the piston F is forcing water in than it will be when the piston E is acting.

Now assuming the pistons E and F to be home at the back ends of their cylinders, as in Fig. 1479, and the press ram also to be at the bottom of its cylinder, it is evident that, if the pipes R and the hydraulic cylinders C and D are filled with water or other fluid practically

1479.



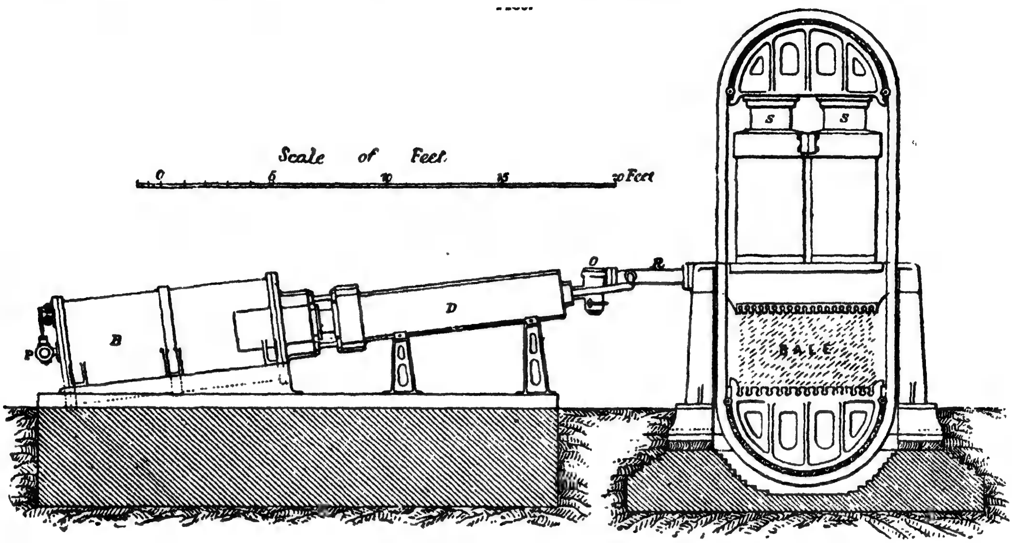
incompressible, any movements of the pistons E and F will move the press ram; and again, supposing that this ram, either by gravity or other means, is caused to return to the bottom of its cylinder, it is clear that the pistons E and F will also return to their former positions; therefore no inlet or outlet valves whatever are required, the same water being forced forwards and backwards between the press ram and the plungers G and H. The admission of steam to the pistons on the one hand, and the weight of the press ram and platen on the other, when the steam is exhausted, acting through the interposed water as a connection, produce the same effect as if the pistons and press ram were mechanically connected together by a rigid coupling.

Fig. 1480 is of a pressure-intensifying apparatus and cotton press in elevation, and Fig. 1479 the same in part sectional plan. Fig. 1481 is a section of the valves P to U, and Fig. 1482 of the valve O.

The two steam cylinders are laid alongside of each other; they may be placed horizontally or vertically, but are preferably placed at a sufficient angle, to cause the pistons and plungers to move readily towards the outer ends of their respective cylinders, when the steam is exhausted.

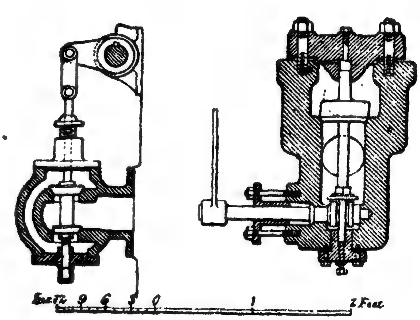
Before commencing to press the bales, steam from the boiler is admitted into the cylinder B, Fig. 1479, by opening the valve P; this drives the piston F, and consequently the plunger H, to the other or front end of the cylinder, thus raising the press rams S S, Fig. 1480, through a corresponding portion of their stroke. This is however only a preliminary stroke for the purpose of heating the cylinder, and enabling the steam just delivered at the back of the piston F, to be trans-

ferred to the other side of it. This is done by closing the pressure valve P, and opening the equilibrium valve Q, through which the steam in the cylinder passes into the pipe M; as it cannot get past the closed inlet valve T on the cylinder A, it passes up the pipe M to the front side of the piston F, which, partly by its own weight and partly by the pressure due to the press rams S S and their platen, transmitted through the water in the press cylinders and pipes, returns to the



outer end of the cylinder B. Supposing that the bale of cotton to be compressed is now placed in the press, the steam which has thus been merely transferred from the back to the front of the piston F, is allowed to enter the cylinder A by means of the valve T, and thus drive the larger hydraulic plunger G forwards. This is done by opening the valve T, when the steam passes from the cylinder B into the cylinder A, driving the piston E, and consequently its plunger G, forward until the pressure in the two steam cylinders is in equilibrium, which of course is the case when the resistance opposed by the pressure on the plunger G, is equal to the pressure of steam on its piston E. As soon as the pressure of steam in the cylinders A and B is equal, the valve T falls by its own weight; and the valve P being opened, fresh steam from the boiler is admitted to the back of the piston F, driving forward the smaller plunger H, any steam on the front side of this piston being exhausted direct into the atmosphere. The increased pressure due to the smaller plunger closes the clack O, Figs. 1480, 1482, which acts as an intermediate check valve between the two water pressures; and thus the finishing pressure is given to the bale, or whatever may be in the press, and if necessary is maintained for any desired length of time.

1481. 1482.



This volume of steam last admitted, after being transferred to the front side of the piston F, furnishes the steam required for the earlier part of the next stroke of the press, which, as before, is done by the plunger G. The press ram being now raised to the height required, the equilibrium valve Q is opened, and the steam at the back of the piston F is transferred to the front of it, as before described; the exhaust valve U and the clack valve O are also opened at the same time, and the steam in the cylinder A is exhausted; the pistons E and F are then in position ready to commence the next pressing operation. The valves are all worked by one man by means of rocking shafts, and suitable means are provided to prevent the pistons E and F from coming into contact with the ends of their cylinders.

The cotton press itself has two cylinders with the rams S S working upwards, Fig. 1480; these raise a crosshead, to which are attached strong wrought-iron links carrying the following table or platen; the casting on which the cylinders rest forms the top platen, and the water being forced into the cylinders raises the lower platen on which is placed the cotton bale, and compresses the latter to the required density.

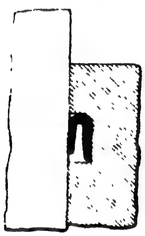
The steam cylinders are each 56 in. diameter; the pressure of steam used is 80 lb. a sq. in.; the area of each piston being 2463 sq. in., this multiplied by 80 gives 197,040 lb. total pressure on one piston. The smaller hydraulic plunger is $9\frac{3}{4}$ in. diameter or 74·66 sq. in. area; and $\frac{197,040}{74 \cdot 66} = 2640$ lb. a sq. in. as the pressure on the plunger. The press has two rams, each

22 in. diameter, the collective area of which = 760 sq. in.; and 760 sq. in. × 2640 lb. a sq. inch = 2,006,400 lb. or 895 tons total pressure on the bale, with 80 lb. a sq. in. steam pressure in the boiler. With a pressure of 3 lb. a sq. in. in the steam cylinder all the weight and friction of parts are overcome; and since each lb. a sq. inch of steam pressure represents a total pressure of 2,006,400 ÷ 80 = 25,080 lb. on the press rams, the total frictional resistances amount to only 75,240 lb., or say 35 tons approximately. Deducting this from the total pressure of 895 tons, there remains 860 tons total effective pressure on the bale. It must not be forgotten moreover, that a part of the dead weight raised is utilized in returning the pistons and rams, after each pressing operation is over.

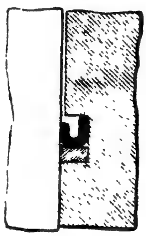
Fig. 1483 is of the packing employed for the rams, Fig. 1469; Fig. 1484, that of the top rams, Fig. 1472.

The durability of a cup-leather depends entirely on how it is applied. In the use of cup-leathers, for quick-running hydraulic pumping engines working under considerable pressure, H. Davey states that as commonly applied the cup-leathers give way very soon; and on investigation he has

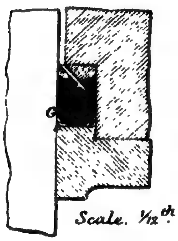
1483.



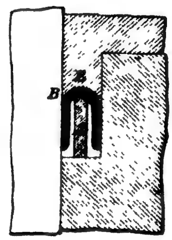
1484.



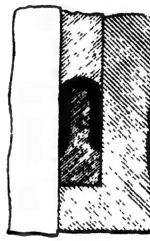
1485.



1486.

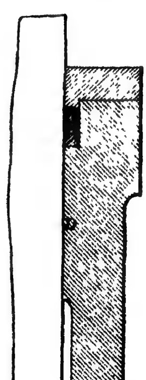


1487.



found that this arises from a springing or buckling action which takes place in the leather, from its not being properly supported. At first it was the custom to drop the leather into the recess, as in Fig. 1486, and support it underneath with a little ring or filling piece A, sometimes of wood and sometimes of cast iron or of brass, rounded to fit the inside of the leather. It was found that the leathers invariably gave way about the point B, and it appeared to Davey that they gave way there from a buckling action: during the upstroke of the ram the leather would be forced hard against it by the pressure until the top of the stroke was reached, and then on the reversal of the stroke until the ram had received a little motion the leather would be stretched in the opposite direction. By putting a brass bush or saddle C, Fig. 1487, under the leather so as to support it effectually underneath, turning the saddle exactly to fit the leather, the leathers will last three or four times as long. Another point which contributes to the life of the leather is to provide a very long bearing for the ram in the cylinder at D, Fig. 1488, immediately below the leather. When thus put in with a more accurate support, the leathers last three or four times as long as they formerly did, when not supported accurately.

1488.



With respect to the material of which packing rings should be made, it appears that for low pressures, and with clean water and well bored cylinders, leather is a good and durable material, and instances are on record where leathers have been at work for more than two years, under a pressure of 750 lb. to the square inch; but if used with dirty water leathers will soon wear out. Welch and Tweddle have made a number of experiments with packing rings shaped in the same U form as cup-leathers, but made of various kinds of materials, including vulcanized indiarubber, guttapercha, and leather. The results showed that indiarubber adhered to the ram and was torn to pieces in a few minutes; guttapercha did not adhere, and lasted fairly well to about one-fifth of the time that leather would, and had the advantage that when worn out it could be remoulded, for it is only necessary to put it into boiling water, add more guttapercha, and then mould it into a fresh ring. With these guttapercha rings they had had a very curious experience. The exterior of the ring had at first been moulded with full square corners at F F in Fig. 1485, while the interior was shaped so that the edge bearing against the ram was nearly twice as thick as the inner edge. When these rings were put into the hydraulic machines, although they were a good fit they were not tight; they leaked, sufficiently to show that they were not acting on the principle on which lipped rings were supposed to act. These identical rings were then taken out, put in a lathe and rounded at the corners; and as soon as that was done they were perfectly tight; showing that for a ring to work at the best advantage, it must be free from the ram at those corners. This would also show that the tightness of the ring did not depend upon the direct pressure of the water behind it forcing it out laterally against the ram, but upon the pressure acting radially to the curve, and resolved into a direction tending to straighten out the semicircular curve of the bottom of the ring, and so giving a thrust in the lateral direction against the ram, as further shown by the fact that the wear took place only at the point G next to the ram. A gun-metal liner J had also been made to fit exactly to the shape of the inside of the ring; and there were a series of holes drilled right into the root of this liner to admit the water well into the interior of the ring. This, however, was not found to make a very great difference, because even without these holes the ring would never fit so tight upon the liner J, but the water would pass in behind it. As to the leather rings, the great defect in many of the

sections employed had been found to be that pointed out by Wilson, namely, that they were made much too deep; it is remarkable how shallow a ring will work with perfect success. From a large number of experiments Welch has deduced the following formulæ, which give what he has found to be the best proportions for leather packing rings;—

$$T = 0\cdot156\,R^{0\cdot279},\quad D = 2\cdot5\,T,\quad W = D;$$

in which R = diameter of ram, T = thickness of leather, D = total depth of ring, W = width of ring outside when of U section. It was absolutely necessary that leather rings should not be strained in the moulding; and Welch found that it was the straining of them, by moulding them too much at one effort, which totally damaged the leather so that it was liable to crack soon afterwards, and to have no durability. He found it necessary to make a series of moulding boxes of successively increasing depth, and to mould the rings by gradual steps; when they passed through the whole series of moulding boxes, much better and more permanent leathers were obtained, and the extra time expended on the mouldings was as nothing when compared with the extra duration of the rings. Ultimately, however, he had entirely done away with the cup-leather rings, and had adopted hemp packing instead, and he used nothing else now. The hemp packing he had used up to a pressure of one ton a sq. in., and it was found to be perfectly tight. He had hemp packing which had been at work for a year without being replenished at all, and there was as yet no sign of leaking.

With regard to the breadth of the packing leathers, Wilson has found a great breadth was so much against the power of the leather to withstand crushing, and the leather is liable to crack and break wherever it becomes at all crushed, therefore he considers that the narrower the leather is the better, so long as it is water-tight. A breadth of only $\frac{1}{8}$ or $\frac{1}{4}$ inch, as shown $\frac{1}{12}$th scale in Fig. 1483, he has found will secure the tightness of the leather quite as effectually as if it were an inch broad. The narrower the leather was, the longer it lasted, because the leather was pressed against the ram with the full pressure of the water behind it; so that the broader the leather was, the greater was the total amount of friction to be overcome, and consequently the force tending to crush the leather longitudinally was proportionally greater, and caused it to be crushed by the friction of the ram. Hence he had had rams covered with gun-metal, whereby less friction was occasioned, because the gun-metal surface was smoother; and by that means economy was obtained in the leather, for where one leather working against a cast-iron ram would be destroyed in a few days, another working on gun-metal would last for months. That was a matter of great importance in the rams. At the bottom, for a length of about 3 ft. from the end, where the heavy pressure came on, they were all covered with gun-metal and highly polished, whereby the wear and tear of the leather was much reduced.

HYDROGEOLOGY.

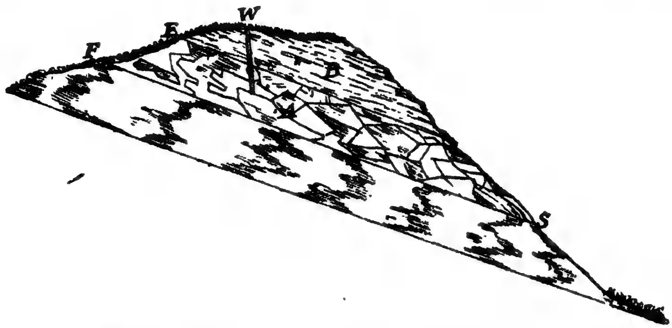
The study of the water-bearing capabilities of various strata is essential to the engineer who has to solve questions relating to the drainage of mines and the sinking of shafts for winning minerals, or for the execution of tunnels, or the supply of water from depths below ground; its object is to group together a number of observed geological facts appertaining to a particular district and consider them for engineering purposes. Water exists in all water-bearing strata in certain forms and positions, and subject to a variation in height, due to the influence of the seasons, and upon a consideration of these questions depend all our calculations relating to the depths of wells and the methods to be adopted in dealing with large beds of underground water.

Nearly every civil engineer is familiar with the fact that certain porous soils, such as sand or gravel, absorb water with rapidity, and that the ground composed of them soon dries up after showers. If a shaft be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching some lower part of the porous formation where it rests on an impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same manner as we see the salt water filtrate into and fill any hollow which we dig in the sands of the shore at low tide. A spring, then, is the lowest point or lip of an underground reservoir of water in the stratification.

The transmission of water through a porous medium being so rapid, we may easily understand why springs are thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, and other permeable substances, while those lying beneath are composed of clay or other retentive soils. The only difficulty, indeed, is to explain why the water does not ooze out everywhere along the line of junction of the two formations so as to form one continuous land-soak, instead of a few springs only, and these oftentimes far distant from each other. The principal cause of such a concentration of the waters at a few points is, first the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels; and secondly, the frequency of rents and fissures, which act as natural drains. That the generality of springs owe their supply to the atmosphere is evident from this, that they vary in the different seasons of the year, becoming languid or entirely ceasing to flow after long droughts, and being again replenished after a continuance of rain. Many of them are probably indebted for the constancy and uniformity of their volume, to the great extent of the subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in all great lakes, for these are not sensibly affected in their levels by a sudden shower, but are only slightly raised, and their channels of efflux, instead of being swollen suddenly like the bed of a torrent, carry off the surplus water gradually.

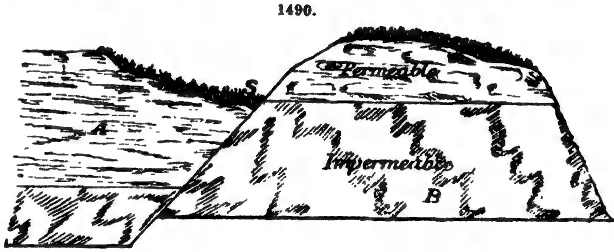
As instances of the way in which the character of the strata may influence the water-bearing capacity of any given locality, we give the following examples;—Fig. 1489 illustrates the causes which sometimes conduce to a limited supply of water in artesian wells. Rain descending on the outcrop E F of the porous stratum A, which lies between the impervious stratum B B, will make its

appearance in the form of a spring at S; but such spring will not yield any great quantity of water, as the area E F, which receives the rainfall, is limited in its extent. A well sunk at W, in a stratum of the above description, would not be likely to furnish a large supply of water, if any. The effect of a fault is shown in Fig. 1490. A spring will in all probability make its appearance at the point S, and give large quantities of water, as the whole body of water flowing through the porous strata



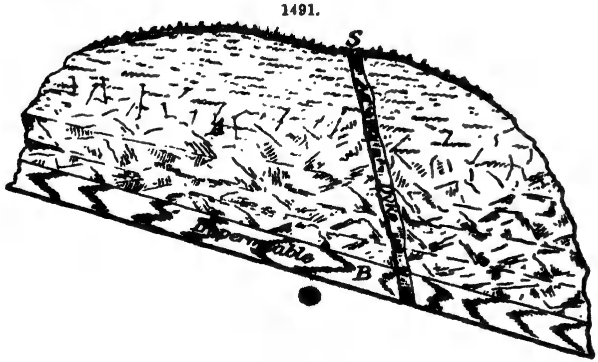
A is intercepted by being thrown against the impermeable stratum B. Permeable rock intersected by a dyke and overlying an impermeable stratum is seen in Fig. 1491. The water flowing through A, if intersected by a dyke D, will appear at S in the form of a spring, and if the area of A is of large extent, then the spring S will be very copious. As to the depth necessary to bore certain wells, in a case similar to Fig. 1492, owing to the fault, a well sunk at A would require to be sunk deeper than the well B, although both wells derive their supply from the same description of strata; or if there is a current of water only in one direction, then one of the wells would prove a failure owing to the proximity of the fault, while the other would furnish an abundant supply of water.

1490.

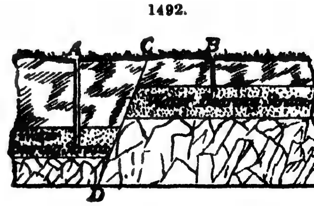


It should be borne in mind that there are two primary geological conditions upon which the quantity of water that may be supplied to the water-bearing strata depends; they are, the extent of superficial area presented by these deposits, by which the quantity of rain-water received on their surface in any given time is determined; and the character and thickness of the strata, as by this the proportion of water that can be absorbed, and the quantity which the whole volume of

1491.



1492.



the permeable strata can transmit, is regulated. The operation of these general principles will constantly vary in accordance with local phenomena, all of which must, in each separate case, be taken into consideration.

The mere distance of hills or mountains need not discourage us from making trials; for the waters which fall on these higher lands readily penetrate to great depths through highly inclined or vertical strata, or through the fissures of shattered rocks; and after flowing for a great distance,

must reascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. The course of water flowing underground is not strictly analogous to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea; whereas, in the other, the water may at one time sink far below the level of the ocean, and afterwards rise again high above it.

For the purposes under consideration, we may range the various strata of which the outer crust of the earth is composed under four heads, namely: 1, drift; 2, alluvion; 3, the tertiary and secondary beds, composed of loose, arenaceous and permeable strata, impervious, argillaceous and marly strata, and thick strata of compact rock, more or less broken up by fissures, as the Norwich red and coralline crag, the Molasse sandstones, the Bagshot sands, the London clay, and the Woolwich beds, in the tertiary division; and the chalk, chalk marl, gault, the greensands, the Wealden clay, and the Hastings sand; the oolites, the lias, the Rhætic beds, and Keuper, and the new red sandstone, in the secondary division; and 4, the primary beds, as the magnesian limestone, the lower red sand, and the coal measures, which consist mainly of alternating beds of sandstones and shales with coal.

The first of these divisions, the drift, consisting mainly of sand and gravel, having been formed by the action of flowing water, is very irregular in thickness, and exists frequently in detached masses. This irregularity is due to the inequalities of the surface at the period when the drift was brought down. Hollows then existing would often be filled up, while either none was deposited on level surfaces, or, if deposited, was subsequently removed by denudation. Hence we cannot infer, when boring through deposits of this character, that the same, or nearly the same, thickness will be found at even a few yards distance. In valleys this deposit may exist to a great depth; the slopes of hills are frequently covered with drift, which has either been arrested by the elevated surface, or brought down from the upper portions of that surface by the action of rain. In the former case the deposits will probably consist of gravel, and in the latter, of the same elements as the hill itself.

The permeability of such beds will, of course, depend wholly upon the nature of the deposit. Some rocks produce deposits through which water percolates readily, while others allow a passage only through such fissures as may exist. Sand and gravel constitute an extremely absorbent medium, while an argillaceous deposit may be wholly impervious. In mountainous districts springs may often be found in the drift; their existence in such formations will, however, depend upon the position and character of the rock strata; thus, if the drift cover an elevated and extensive slope of a nature similar to that of the rocks by which it is formed, springs due to infiltration through this covering will certainly exist near the foot of the slope. Upon the opposite slope, the small spaces which exist between the different beds of rock receive these infiltrations directly, and serve to completely drain the deposit which, in the former case, is, on the contrary, saturated with water. If, however, the foliations or the joints of the rocks afford no issue to the water, whether such a circumstance be due to the character of their formation, or to the stopping up of the issues by the drift itself, these results will not be produced.

It will be obvious how, in this way, by passing under a mass of drift, the water descending from the top of hill slopes reappears at their foot in the form of springs. If now we suppose these issues stopped, or covered by an impervious stratum of great thickness, and this stratum pierced by a boring, the water will ascend through this new outlet to a level above that of its original issue, in virtue of the head of water, measured from the points at which the infiltration takes place, to the point in which it is struck by the boring.

Alluvion, like drift, consists of fragments of various strata carried away and deposited by flowing water; it differs from the latter only in being more extensive and regular, and, generally, in being composed of elements brought from a great distance, and having no analogy with the strata with which it is in contact. Usually it consists of sand, gravel, rolled pebbles, marls or clays. The older deposits often occupy very elevated districts, which they overlie throughout a large extent of surface. At the period when the large rivers were formed, the valleys were filled up with alluvial deposits, which at the present day are covered by vegetable soil, and a rich growth of plants, through which the water percolates more slowly than formerly. The permeability of these deposits allows the water to flow away subterraneously to a great distance from the points at which it enters. Springs are common in the alluvion, and, more frequently than in the case of drift, they can be found by boring. As the surface, which is covered by the deposit, is extensive, the water circulates from a distance through permeable strata often overlaid by others that are impervious. If at a considerable distance from the points of infiltration, and at a lower level, a boring be put down, the water will ascend in the bore-hole in virtue of its tendency to place itself in equilibrium. Where the country is open and uninhabited, the water from shallow wells sunk in alluvion is generally found to be good enough and in sufficient quantity for domestic purposes. The strata of the tertiary and secondary beds, especially the latter, are far more extensive than the preceding, and yield much larger quantities of water. The chalk is the great water-bearing stratum for the larger portion of the south of England. The water in it can be obtained either by means of ordinary shafts, or by Artesian wells bored sometimes to great depths, from which the water will frequently rise to the surface. It should be observed that water does not circulate through the chalk by general permeation of the mass, but through fissures. A rule given by some for the level at which water may be found in this stratum is: "Take the level of the highest source of supply, and that of the lowest to be found. The mean level will be the depth at which water will be found at any intermediate point, after allowing an inclination of at least 10 feet a mile." This rule will also apply to greensand. This formation contains large quantities of water, which is more evenly distributed than in the chalk. The gault clay is interposed between the upper and the lower greensand, the latter of which also furnishes good supplies. In boring into the upper greensand,

caution should be observed so as not to pierce the gault clay, because water which permeates through that system becomes either ferruginous, or contaminated by salts and other impurities.

The next strata in which water is found are the upper and inferior oolites, between which are the Kimmeridge and Oxford clays, which are separated by the coral rag. There are instances in which the Oxford clay is met with immediately below the Kimmeridge, rendering any attempt at boring useless, because the water in the Oxford clay is generally so impure as to be unfit for use. And with regard to finding water in the oolite limestone, it is impossible to determine with any amount of precision the depth at which it may be reached, owing to the numerous faults which occur in the formation. It will therefore be necessary to employ the greatest care before proceeding with any borings. Lower down in the order are the upper lias, the marlstone, the lower lias, and the new red sandstone. In the marlstone, between the upper and lower beds of the lias, there may be found a large supply of water, but the level of this is as a rule too low to rise to the surface through a boring. It will be necessary to sink shafts in the ordinary way to reach it.

In the new red sandstone, to find the water, borings must be made to a considerable depth, but when this formation exists a copious supply may be confidently anticipated, and when found the water is of excellent quality. This formation is, next to the chalk and lower greensand, the most extensive source of water supply from wells in England, and although the two formations mentioned occupy a larger area, yet, owing to geographical position, the new red sandstone receives a more considerable quantity of rainfall, and, owing to the comparative scarceness of carbonate of lime, yields softer water.

The new red sandstone is called on the Continent "the Trias," as in Germany and parts of France it presents a distinct threefold division. Although the names of each of the divisions are commonly used, they are in themselves local and unessential, as the same exact relations between them do not occur in other remote parts of Europe as in England, and are not to be looked for in distant continents. The names of the divisions and their English equivalents are;—

Keuper, or red marls.

Muschelkalk, or shell limestones, not found in this country.

Bunter sandstone, or variegated sandstone.

The strata consist in general of red, mottled, purple or yellowish sandstones and marls, with beds of rock-salt, gypsum pebbles, and conglomerate.

The region over which triassic rocks outcrop in England, stretches across the island from a point in the south-western part of the English Channel about Exmouth, Devon, north-north-eastward, and also from the centre of this band along a north-westward course to Liverpool, thence dividing and running north-east to the Tees, and north-west to Solway Firth.

In Central Europe the trias is found largely developed, and in North America it covers an area whose aggregate length is some 700 or 800 miles.

The beds, in England, may be divided as follows;—

		Average thickness.
Keuper—	Red marls, with rock-salt and gypsum	1000 ft.
	Lower Keuper sandstones, with trias sandstones and marls, waterstones	250 "
	Dolomitic conglomerate..	000 "
Bunter—	Upper red and mottled sandstone	300 "
	Pebble beds, or uncompacted conglomerate	300 "
	Lower red and mottled sandstone	250 "

The Keuper series is introduced by a conglomerate often calcareous, passing up into brown, yellow, or white greenstone, and then into thinly laminated sandstones and marls. The other subdivisions are remarkably uniform in character, except in the case of the pebble beds, which in the north-west form a light red pebbly building stone, but in the central counties becomes generally an unconsolidated conglomerate of quartzose pebbles.

The following tabulated form, due to Edward Hull, shows the comparative thickness and range of the triassic series along a south-easterly direction from the estuary of the Mersey, and also shows the thinning away of all the triassic strata from the north-west towards the south-east of England, which Hull was amongst the first to demonstrate.

Table I.—Thickness and Range of the Trias in a South-easterly Direction from the Mersey.

Names of Strata.		Lancashire and West Cheshire.	Staffordshire.	Leicestershire and Warwickshire.
		feet.	feet.	feet.
Keuper series—	Red marl	3000	800	700
	Lower Keuper sandstone ..	450	200	150
Bunter series—	Upper mottled sandstone ..	500	50–200	absent.
	Pebble beds	500–750	100–300	0–100
	Lower mottled sandstone ..	200–500	0–100	absent.

The formation may be looked upon as almost equally permeable in all directions, and the whole mass may be regarded as a reservoir up to a certain level, from which, whenever wells are sunk, water will always be obtained more or less abundantly. This view is very fairly borne out by experience, and the occurrence of the water is certainly not solely due to the presence of the fissures or joints traversing the rock, but to its permeability, which, however, varies in different districts. In the neighbourhood of Liverpool the rock, or at least the pebble bed, is less porous than in the

neighbourhood of Whitmore, Nottingham, and other parts of the Midland Counties, where it becomes either an unconsolidated conglomerate or a soft crumbly sandstone. Yet wells sunk even in the hard building stone of the pebble beds, either in Cheshire or Lancashire, always yield water at a certain variable depth. Beyond a certain depth the water tends to decrease, as was the case in the St. Helen's public well, situated on Eccleston Hill. At this well an attempt was made, in 1868, to increase the supply by boring deeper into the sandstone, but without any good result. When water percolates downwards in the rock we may suppose there are two forces of an antagonistic character brought into play; there is the force of friction, increasing with the depth, and tending to hinder the downward progress of the water, while there is the hydrostatic pressure tending to force the water downwards, and we may suppose that when equilibrium has been established between these two forces, the further percolation will cease.

The proportion of rain which finds its way into the rock in some parts of the country must be very large. When the rock, as is generally the case in Lancashire, Cheshire, and Shropshire, is partly overspread by a coating of dense boulder clay, almost impervious to water, the quantity probably does not exceed one-third of the rainfall over a considerable area; but in some parts of the Midland Counties, where the rock is very open, and the covering of drift scanty or altogether absent, the percolation amounts to a much larger proportion, probably one-half or two-thirds, as all the rain which is not evaporated passes downwards. The new red sandstone, as remarked, may be regarded, in respect to water supply, as a nearly homogenous mass, equally available throughout; and it is owing to this structure, and the almost entire absence of beds of impervious clay or marl, that the formation is capable of affording such large supplies of water; for the rain which falls on its surface and penetrates into the rock is free to pass in any direction towards a well when sunk in a central position. If we consider the rock as a mass completely saturated with water through a certain vertical depth, the water being in a state of equilibrium, when a well is sunk, and the water pumped up, the state of equilibrium is destroyed, and the water in the rock is forced in from all sides.

The percolation is, doubtless, much facilitated by joints, fissures, and faults, and in cases where one side of a fault is composed of impervious strata, such as the Keuper marls, or coal measures, the quantity of water pent up against the face of the fault may be very large, and the positions often favourable for a well. An instance of the effect of faults in the rock itself, in increasing the supply, is afforded in the case of the well at Flaybrick Hill, near Birkenhead. From the bottom of this well a heading was driven at a depth of about 160 ft. from the surface, to cut a fault about 150 ft. distant, and upon this having been effected the water flowed in with such impetuosity that the supply, which had been 400,000 gals. a day, was at once doubled.

The water from the new red sandstone is clear, wholesome, and pleasant to drink; it is also well adapted for the purposes of bleaching, dyeing, and brewing; at the same time it must be admitted that its qualities as regards hardness, in other words, the proportions of carbonates of limes and magnesia it contains, are subject to considerable variation, depending on the locality and composition of the rock. As a general rule, the water from the new red sandstone may be considered as occupying a position intermediate between the hard water of the chalk, and the soft water supplied to some of our large towns from the drainage of mountainous tracts of the primary formations, of which the water supplied from Loch Katrine to Glasgow is perhaps the purest example, containing only 2·35 grains of solid matter to the gallon. Having besides but a small proportion of saline ingredients, which, while they tend to harden the water, are probably not without benefit to the animal economy, the water supply from the new red sandstone possesses incalculable advantages over that from rivers and surface drainage. Many of our large towns are now partially or entirely supplied with water pumped from deep wells in this sandstone; and several from copious springs gushing forth from the rock at its junction with some underlying impervious stratum belonging to the primary series.

Every permeable stratum may yield water, and its ability to do this, and the quantity it can yield, depend upon its position and extent. When underlaid by an impervious stratum, it constitutes a reservoir of water from which a supply may be drawn by means of a sinking or a bore-hole. If the permeable stratum be also overlaid by an impervious stratum, the water will be under pressure and will ascend the bore-hole to a height that will depend on the height of the points of filtration above the bottom of the bore-hole. The quantity to be obtained in such a case, as we have already pointed out, will depend upon the extent of surface possessed by the outcrop of the permeable stratum. In searching for water under such conditions a careful examination of the geological features of the district must be made. Frequently an extended view of the surface of the district, such as may be obtained from an eminence, and a consideration of the particular configuration of that surface, will be sufficient to enable the practical eye to discover the various routes which are followed by the subterranean water, and to predicate with some degree of certainty that at a given point water will be found in abundance, or that no water at all exists at that point. To do this, it is sufficient to note the dip and the surfaces of the strata which are exposed to the rains. When these strata are nearly horizontal, water can penetrate them only through their fissures or pores; when, on the contrary, they lie at right angles, they absorb the larger portion of the water that falls upon their outcrop. When such strata are intercepted by valleys numerous springs will exist. But if, instead of being intercepted, the strata rise around a common point, they form a kind of irregular basin, in the centre of which the water will accumulate. In this case the surface springs will be less numerous than when the strata are broken. But it is possible to obtain water under pressure in the lower portions of the basin if the point at which the trial is made is situate below the outcrop.

The primary rocks afford generally but little water. Having been subjected to violent convulsions, they are thrown into every possible position and broken by numerous fissures; and as no permeable stratum is interposed, as in the more recent formations, no reservoir of water exists. In the unstratified rocks, the water circulates in all directions through the fissures that traverse them, and

thus occupies no fixed level. It is also impossible to discover by a surface examination where the fissures may be struck by a boring. For purposes of water supply, therefore, these rocks are of little importance. It must be remarked here, however, that large quantities of water are frequently met with in the magnesian limestone and the lower red sand, which form the upper portion of the primary series.

Joseph Prestwich, jun., in his 'Geological Inquiry respecting the Water-bearing Strata round London,' gives the following valuable epitome of the geological conditions affecting the value of water-bearing deposits; and, although the illustrations are confined to the tertiary deposits, the same mode of inquiry will apply with but little modification to any other formation.

The main points are;—

The extent of the superficial area occupied by the water-bearing deposit.

The lithological character and thickness of the water-bearing deposit, and the extent of its underground range.

The position of the outcrop of the deposit, whether in valleys or hills, and whether its outcrop is denuded, or covered with any description of drift.

The general elevation of the country occupied by this outcrop above the levels of the district in which it is proposed to sink wells.

The quantity of rain which falls in the district under consideration, and whether, in addition, it receives any portion of the drainage from adjoining tracts, when the strata are impermeable.

The disturbances which may affect the water-bearing strata, and break their continuous character, as by this the subterranean flow of water would be impeded or prevented.

To proceed to the application of the questions in the particular instance of the lower tertiary strata. With regard to the first question, it is evident that a series of permeable strata encased between two impermeable formations can receive a supply of water at those points only where they crop out and are exposed on the surface of the land. The primary conditions affecting the result depend upon the fall of rain in the district where the outcrop takes place; the quantity of rain-water which any permeable strata can gather being in the same ratio as their respective areas. If the mean annual fall in any district amounts to 24 in., then each square mile will receive a daily average of 950,947 gallons of rain water. It is therefore a matter of essential importance to ascertain, with as much accuracy as possible, the extent of exposed surface of any water-bearing deposit, so as to determine the maximum quantity of rain water it is capable of receiving.

The surface formed by the outcropping of any deposit in a country of hill and valley is necessarily extremely limited, and it would be difficult to measure in the ordinary way. Prestwich therefore used another method, which seems to give results sufficiently accurate for the purpose. It is a plan borrowed from geographers, that of cutting out from a map on paper of uniform thickness and on a large scale, say one inch to the mile, and weighing the superficial area of each deposit. Knowing the weight of a square of 100 miles cut out of the same paper, it is easy to estimate roughly the area in square miles of any other surface, whatever may be its figure.

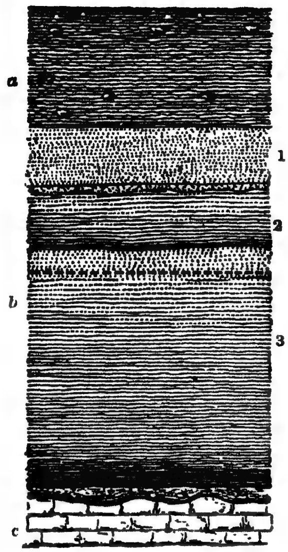
Mineral Character of the Formation.—The second question relates to the mineral character of the formation, and the effect it will have upon the quantity of water which it may hold or transmit.

If the strata consist of sand, water will pass through them with facility, and they will also hold a considerable quantity between the interstices of their component grains; whereas a bed of pure clay will not allow of the passage of water. These are the two extremes of the case; the intermixture of these materials in the same bed will of course, according to their relative proportions, modify the transmission of water. Prestwich found by experiment that a siliceous sand of ordinary character will hold on an average rather more than one-third of its bulk of water, or from two to two and a half gallons in one cubic foot. In strata so composed the water may be termed free, as it passes easily in all directions, and under the pressure of a column of water is comparatively but little impeded by capillary attraction. These are the conditions of a true permeable stratum. Where the strata are more compact and solid as in sandstone, limestone, and oolite, although all such rocks imbibe more or less water, yet the water so absorbed does not pass freely through the mass, but is held in the pores of the rock by capillary attraction, and parted with very slowly; so that in such deposits water can be freely transmitted only in the planes of bedding and in fissures. If the water-bearing deposit is of uniform lithological character over a large area, then the proposition is reduced to its simplest form; but when, as in the deposit between the London clay and the chalk, the strata consist of variable mineral ingredients, it becomes essential to estimate the extent of these variations; for very different conclusions might be drawn from an inspection of the lower tertiary strata at different localities.

In the fine section exposed in the cliffs between Herne Bay and the Reculvers, in England, a considerable mass of fossiliferous sands is seen to rise from beneath the London clay. Fig. 1493 represents a view of a portion of this cliff a mile and a half east of Herne Bay and continued downwards, by estimation, below the surface of the ground to the chalk. In this section there is evidently a very large proportion of sand, and consequently a large capacity for water. Again, at Upnor, near Rochester, the sands marked 3 are as much as 60 to 80 ft. thick, and continue so to Gravesend, Purfleet, and Erith. In the first of these places they may be seen capping Windmill Hill; in the second, forming the hill, now removed, on which the lighthouse is built; and in the third, in the large ballast pits on the banks of the River Thames. The average thickness of these sands in this district may be about 50 to 60 ft. In their range from east to west, the beds 2 become more clayey and less permeable, and 1, very thin. As we approach London, the thickness of 3 also diminishes. In the ballast pits at the west end of Woolwich, this sand-bed is not more than 35 ft. thick, and as it passes under London becomes still thinner.

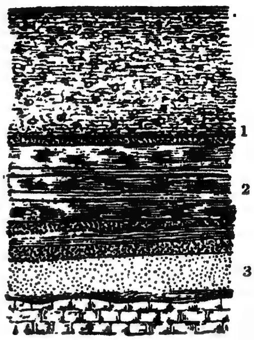
Fig. 1494 is a general or average section of the strata on which London stands. The increase in the proportion of the argillaceous strata and the decrease of the beds of sand, in the lower tertiary strata, is here very apparent, and from this point westward to Hungerford, clays decidedly predominate; while at the same time the series presents such rapid variations, even on the same

level and at short distances, that no two sections are alike. On the southern boundary of the tertiary district, from Croydon to Leatherhead, the sands 3 maintain a thickness of 20 to 40 ft., whilst the associated beds of clay are of inferior importance. We will take another section, Fig. 1495, representing the usual features of the deposit in the northern part of the tertiary district.



a. London clay.
b. Sands and clay. *c.* Chalk.

1494.



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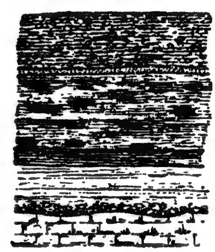
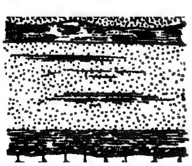


It is from a cutting at a brickfield west of the small village of Hedgerley, six miles northward of Windsor.

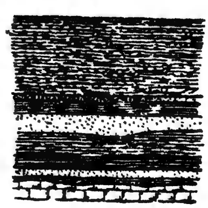
Here we see a large development of the mottled clays, and but little sand. A somewhat similar section is exhibited at Oak End, near Chalfont St. Giles. But to show how rapidly this series changes its character, the section of a pit only a third of a mile westward of the one at Hedgerley is given in Fig. 1496.

In this latter section the mottled clays have nearly disappeared, and are replaced by beds of sand with thin seams of mottled clays. At Twyford, near Reading, and at Old Basing, near Basingstoke, the mottled clays again occupy, as at Hedgerley, nearly the whole space between the London clays and the chalk. Near Reading, a good section of these beds was exhibited in the Sonning cutting of the Great Western Railway; they consisted chiefly of mottled clays. At the Katsgrove Pits, Reading, the beds are more sandy. Referring back to Fig. 1494, it may be noticed that there is generally a small quantity of water found in the bed marked 1 in parts of the

1496.



1497.



neighbourhood of London. Owing, however, to the constant presence of green and ferruginous sands, traces of vegetable matters and remains of fossil shells, the water is usually indifferent and chalybeate. The well-diggers term this a slow spring. They well express the difference by saying that the water creeps up from this stratum, whereas that it bursts up from the lower sands 3, which is the great water-bearing stratum. In the irregular sand beds interstratified with the mottled clays between these two strata water is also found, but not in any large quantity.

Fig. 1497 is a section at the western extremity of the tertiary district at Pebble Hill, near Hungerford. Here again the mottled clays are in considerable force, sands forming the smaller part of the series.

The Tables II. and III. exhibit the aggregate thickness of all the beds of sand between the

London clay and the chalk at various localities in the tertiary district. It will appear from them that the mean results of the whole are very different from any of those obtained in separate divisions of the country. The mean thickness of the deposit throughout the whole tertiary area may be taken at 62 ft., of which 36 ft. consists of sands and 26 ft. of clays; but as only a portion of this district contributes to the water supply of London, it will facilitate our inquiry if we divide it into two parts, the one westward of and including London, the other eastward of it, introducing also some further subdivisions into each.

Table II.—Measurement of Sections Eastward of London.

Southern Boundary.	Sand.	Clay.	Northern Boundary.	Sand.	Clay.
	ft.	ft.		ft.	ft.
Lewisham	65	26	Hertford	26	3
Woolwich	66	18	Beaumont Green, near Hoddesdon	16	10
Upnor	80?	8	Broxbourne	28	2
Herne Bay	70?	50	Gestingthorpe, near Sudbury ..	50?	?
			Whitton, near Ipswich	60?	5
Average	70	25	Average	36	5

The mean of the three columns in two western sections gives a thickness to this formation of 57 ft., of which only 19 ft. are sand and permeable to water, and the remaining 38 ft. consist of impermeable clays, affording no supply of water.

The area, both at the surface and underground, over which they extend, is about 1086 square miles.

Table III.—Measurement of Sections Westward of London.

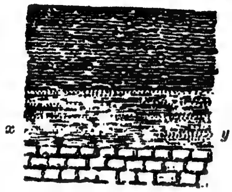
On or near the Southern Boundary of the Tertiary District.	Sand.	Clay.	On a Central Line in the Tertiary District.	Sand.	Clay.	On or near the Northern Boundary of the Tertiary District.	Sand.	Clay.
	ft.	ft.	Sand. Clay. ft. ft.	ft.	ft.		ft.	ft.
Streatham	30	25	London :—			Hatfield	23	2
Mitcham	47	34	Millbank .. 49 40			Watford	25	10
Croydon	35?	20?	Trafalgar Square .. 49 30			Pinner	12	32
Epsom	31	23	Tottenham Court Road 35 30			Oak End, Chalfont St. Giles	3	40
Fetcham	35	20	Pentonville .. 34 44	46	39	Hedgerley, near Slough	5	45
Guildford	10?	40	Barclay's Brewery .. 55 42			Starveall " "	13	20
Chinham, near Basingstoke ..	20?	30	Lombard Street .. 53 35			Twyford	5	60
Itchingswell, near Kingsclere ..	22	34	The Mint .. 49 38			Sonning, near Reading	12	54
Highclere	24	27	Whitechapel 45 50			Reading	16	33
Pebble Hill, near Hungerford ..	9	39	Garrett, near Wandsworth	20	52	Newbury	20	36
			Isleworth	17	70	Pebble Hill	9	39
			Twickenham	7	50			
			Chobham	3	45			
Average ..	26	29	Average	18	51	Average	13	34

The average total thickness of the eastern district deduced from the nine sections we have taken gives 68 ft., of which 53 ft. are sands and 15 ft. clays. The larger area, 1849 square miles, over which the eastern portion of the tertiary series extends, and the greater volume of the water-bearing beds, constitute important differences in favour of this district; and if there had been no geological disturbances to interfere with the continuous character of the strata, we might have looked to this quarter for a large supply of water to the artesian wells of London.

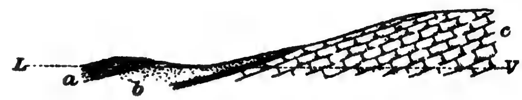
From these tables it will be readily perceived that the strata of which the water-bearing deposits are composed are very variable in their relative thickness. They consist, in fact, of alternating beds of clay and sand, in proportions constantly changing. In one place, as at Hedgerley, the aggregate beds of sand may be 5 ft. thick, and the clays 45 ft.; whilst at another, as at Leatherhead, the sands may be 35 and the clays 20 ft. thick, and some such variation is observable in every locality. But although we may thus in some measure judge of the capacity of these beds for water, this method fails to show whether the communication from one part of the area to another is free, or impeded by causes connected with mineral character. Now as we know that these beds not only vary in their thickness, but that they also frequently thin out, and sometimes pass one into another, it may happen that a very large development of clay at any one place may altogether stop the transit of the water in that locality. Thus in Fig. 1498 the beds of sand at *y* allow of the free passage of water, but at *x*, where clays occupy the whole thickness, it cannot

pass; the obstruction which this cause may offer to the underground flow of water can only be determined by experience. It must not, however, be supposed that such a variation in the strata is permanent or general along any given line. It is always local, some of the beds of clay commonly thinning out after a certain horizontal range, so that, although the water may be impeded or retarded in a direct course, it most probably can, in part altogether, pass round by some point where the strata have not undergone the same alteration.

Position and General Conditions of the Outcrop.—This involves some considerations to which an exact value cannot at present be given, yet which require notice, as they to a great extent determine the proportion of water which can pass from the surface into the mass of the water-



1499.



bearing strata. In the first place, when the outcrop of these strata occurs in a valley, as represented in Fig. 1499, it is evident that *b* may not only retain all the water which might fall on its surface, but also would receive a proportion of that draining off from the strata of *a* and *c*. This form of the surface generally prevails wherever the water-bearing strata are softer and less coherent than the strata above and below them.

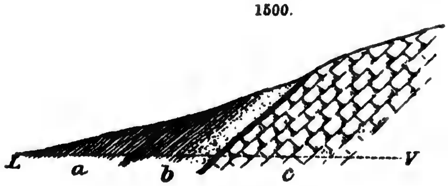
It may be observed in the lower tertiary series at Sutton, Carshalton, and Croydon, where a small, shallow valley, excavated in these sands and mottled clays, ranges parallel with the chalk hills.

It is apparent again between Epsom and Leatherhead, and also in some places between Guildford and Farnham, as well as between Odiham and Kingsclere. The Southampton Railway crosses this small valley on an embankment at Old Basing.

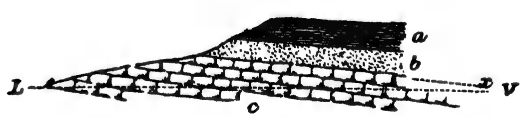
This may be considered as the prevailing, but not exclusive, form of structure from Croydon to near Hungerford. The advantage, however, to be gained from it in point of water-supply is much limited by the rather high angle at which the strata are inclined, as well as by their small development, which greatly restrict the breadth of the surface occupied by the outcrop. It rarely exceeds a quarter of a mile, and is generally very much less, often not more than 100 to 200 feet. The next modification of outcrop, represented in Fig. 1500, is one not uncommon on the south side of the tertiary district. The strata *b* here crop out on the slope of the chalk hills, and the rain falling upon them, unless rapidly absorbed, tends to drain at once from their surface into the adjacent valleys. V, L shows the line of valley level.

This arrangement is not unfrequent between Kingsclere and Inkpen, and also between Guildford and Leatherhead. Eastward of London it is exhibited on a larger scale at the base of the chalk hills, in places between Chatham and Faversham, a line along which the sands of the lower

1500.



1501.



tertiary strata, *b*, are more fully developed than elsewhere. As, however, the surface of *b* is there usually more coincident with the valley level, V, L, of the district, it is in a better position for retaining more of the rainfall.

A third position of outcrop, much more unfavourable for the water-bearing strata, prevails generally along the greater part of the northern boundary of the tertiary strata. Instead of forming a valley, or outcropping at the base of the chalk hills, almost the whole length of this outcrop lies on the slope of the hills, as in Fig. 1501, where the chalk *c* forms the base of the hill and the lower ground at its foot, whilst the London clay, *a*, caps the summit, thus restricting the outcrop of *b* to a very narrow zone and a sloping surface. This form of structure is exhibited in the hills round Sonning, Reading, Hedgerley, Rickmansworth, and Watford; thence by Shenley Hill, Hatfield, Hertford, Sudbury; and also at Hadleigh this position of outcrop is continued. If, as on the southern side of the tertiary district, the outcrop were continued in a nearly unbroken line, then these unfavourable conditions would prevail uninterruptedly; but the hills are in broken groups, and intersected at short distances by transverse valleys, as that of the Kennet at Reading, of the Loddon at Twyford, of the Colne at Uxbridge, and so on. Between Watford and Hatfield there is a constant succession of small valleys running back for short distances from the lower district of the chalk, through the hills of the tertiary district. The valley of the Lea at Roydon and Hoddesdon is a similar and stronger case in point. The effect of these transverse valleys is to point out a larger surface of the strata *b* than would otherwise be exposed, for if the horizontal line

V L, Fig. 1501, were carried back beyond the point x to meet the prolongation of b, then these lower tertiary strata would not only be intersected by the line of valley level, but would form a much smaller angle with the plane V L, and therefore spread over a larger area than where they crop out on the side of the hills.

The foregoing are the three most general forms of outcrop, but occasionally the outcrop takes place wholly or partially on the summit of a hill, as, near the Reculvers, in the neighbourhood of Canterbury, of Sittingbourne, and at the Addington Hills, near Croydon, in which cases the area of the lower tertiary is expanded. When the dip is very slight, and the beds nearly horizontal, the lower tertiary sands occasionally spread over a still larger extent of surface, as between Stoke Pogis, Burnham Common, and Beaconsfield, and in the case of the flat-topped hill, forming Blackheath and Bexley Heath, as in Fig. 1502. Favourable as such districts might at first appear to be from the extent of their exposed surface, nevertheless they rarely contribute to the water supply

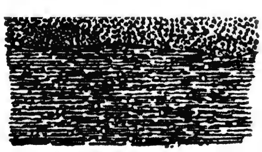
of the wells sunk into the lower tertiary sands under London, the continuity of the strata being broken by intersecting valleys; thus the district last mentioned is bounded on the north by the valley of the Thames, on the west by that of Ravensbourne, and on the east by the valley of the Cray; consequently the rain water, which has been absorbed by the very permeable strata on the intermediate higher ground, passes out on the sides of the hills, into the square channels in the valleys, or into the chalk. Almost all the wells at Bexley Heath, for their supply of water, have, in fact, to be sunk into the chalk through the overlying 100 to 133 ft. of sand and pebble beds b.

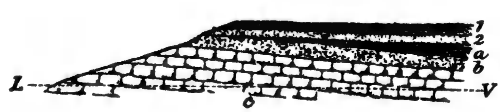
Thus far we have considered this question as if, in each instance, the outcropping edges of the water-bearing strata, b, were laid bare, and presented no impediment to the absorption of the rain-water falling immediately upon their surface, or passing on to it from some more impermeable deposits. But there is another consideration which influences materially the extent of the water supply.

If the strata b were always bare, we should have to consider their outcrop as an absorbent surface, of power varying according to the lithological character and dip of the strata only. But the outcropping edges of the strata do not commonly present bare and denuded surfaces. Thus a large extent of the country round London is more or less covered by beds of drift, which protect the outcropping beds of b, and turn off a portion of the water falling upon them.

The drift differs considerably in its power of interference with the passage of the rain water into the strata beneath. The ochreous sandy flint gravel, forming so generally the subsoil of London, admits of the passage of water. All the shallow surface springs, from 10 to 20 ft. deep, are produced by water which has fallen on, and passed through, this gravel, g, Fig. 1503, down to the top of the London clay, a, on the irregular surface of which it is held up.

When the London clay is wanting, this gravel lies immediately upon the lower tertiary strata, as in the valley between Windsor and Maidenhead, and in that of the Kennet between Newbury and Thatcham, transmitting to the underlying strata part of the surface water. Where beds of brick earth occur in the drift, as between West Drayton and Uxbridge, the passage of the surface water





into the underlying strata is intercepted. Sometimes the drift is composed of gravel mixed very irregularly with broken-up London clay, and although commonly not more than 3 to 8 ft. thick, it is generally impermeable. Over a considerable portion of Suffolk and part of Essex, a drift, composed of coarse and usually light-coloured sand with fine gravel, occurs. Water percolates through it with extreme facility, but is generally covered by a thick mass of stiff tenacious bluish-grey clay, perfectly impervious. This clay drift, or boulder clay, caps, to a depth of from 10 to 50 ft. or more, almost all the hills in the northern division of Essex, and a large portion of Suffolk and Norfolk. It so conceals the underlying strata that it is difficult to trace the course of the outcrop of the lower tertiary sands between Ware and Ipswich; and often, as in Fig. 1504, notwithstanding the breadth, apart from this cause of the outcrop of the tertiary sands, b, and of the drift of sand and gravel, 2, they are both so covered by the boulder clay, 1, that the small surface exposed can be of comparatively little value.

There are also, in some valleys, river deposits of silt, mud, and gravel. These are, however, of little importance to the subject before us. Under ordinary conditions they are generally sufficiently impervious to prevent the water from passing through the beds beneath.

The height of the districts, wherein the water-bearing strata crop out, above that of the surface of the country in which the wells are placed, should be made the subject of careful consideration, as upon this point depends the level to which the water in shafts or wells may ascend. When inquiring into the probable relative value of any water-bearing strata, it is necessary to compare the rainfall in their respective districts.

The last question to be considered relates to the disturbances which may have affected the strata; for whatever may be the absorbent power of the strata, the yield of water will be more or less diminished whenever the channels of communication have suffered break or fracture.

If the strata remained continuous and unbroken, we should merely have to ascertain the dimensions and lithological character; if the strata is broken, the interference with the subterranean transmission of water will be proportionate to the extent of the disturbance.

Although the tertiary formations around London have probably suffered less from the action of disturbing forces than the strata of any other district of the same extent in England, yet they nevertheless now exhibit considerable alterations from their original position.

The principal change has been that which, by elevation of the sides or depression of the centre of the district, gave the tertiary deposits their present trough-shaped form, assuming it not to be the result of original deposition. If no further change had taken place, we might have expected to find an uninterrupted communication in the lower tertiary strata from their northern outcrop at Hertford to their southern outcrop at Croydon, as well as from Newbury on the west to the sea on the east; and the entire length of 260 miles of outcrop would have contributed to the general supply of water at the centre.

But this is far from being the case; several disturbing causes have deranged the regularity of original structure. The principal one has caused a low axis of elevation, or rather line of flexure running east and west, following nearly the course of the Thames from the Nore to Deptford, and apparently continued thence beyond Windsor. It brings up the chalk at Cliff, Purfleet, Woolwich, and Loampit Hill to varied but moderate elevations above the river level. Between Lewisham and Deptford the chalk disappears below the tertiary series, and does not come to the surface till we reach the neighbourhood of Windsor and Maidenhead.

There is also, probably, another line of disturbance running between some points north and south, and intersecting the first line at Deptford. It passes apparently near Beckenham and Lewisham, and then, crossing the Thames near Deptford, continues up a part, if not along the whole length of the valley of the Lea towards Hoddesdon. This disturbance appears in some places to have resulted in a fracture or a fault in the strata, placing the beds on the east of it on a higher level than those on the west: and at other places merely to have produced a curvature in the strata. Prestwich states that he was unable to give its exact course, but its effect, at all events upon the water supply of London, is important, as, in conjunction with the first or Thames valley disturbance, it cuts off the supplies from the whole of Kent, and interferes most materially with the supply from Essex; for in its course up the valley of the Lea it either brings up the lower tertiary strata to the surface, as at Stratford and Bow, or else, as farther up the valley, it raises them to within 40 or 60 ft. of the surface.

The tertiary district thus appears, on a general view, to be divided naturally into four portions by lines running nearly north and south, the former line passing immediately south, and the latter east of London, which stands at the south-east corner of the north-western division, and consequently it must not be viewed as the centre of one large and unbroken area, so far as the tertiary strata are concerned.

INDICATOR.

In testing or experimenting with a steam engine we are compelled, in most cases, to accept as final the results given by the indicator. Only now and then do circumstances allow a comparison to be made between a pressure measured directly, and the same pressure estimated from the compression of the spring, and even in these few cases the direct measurement of the pressure is generally made only by a Bourdon gauge, which, if there be a discrepancy, is quite as likely to be incorrect as the indicator spring. It is seldom possible to check the indications of a spring, or obtain an approximate value to its error.

Berndt, of Chemnitz, has however, during 1874–76, made a series of experiments, which are of importance, as to the matter in question.

These investigations were intended to give information as to how far the springs are, in themselves, perfectly elastic within their working limits, both at the usual temperature and when heated; how far their whole behaviour in the indicator cylinder, under steam, agrees with or differs from their behaviour when tested free, hot or cold; to what extent such differences could be traced to piston friction, pencil friction, or other more or less preventible or measurable causes; whether the scales supplied and commonly used with the springs gave really correct readings, within reasonable limits of error, and if not how more accurate readings could be obtained; whether the varying extension on the spring caused any appreciable error.

The first series of experiments had for its object to test how far the elasticity of the springs themselves, independently altogether of the indicators, was perfect, how far, that is, the compression of the springs was proportional to the pressure acting upon them, and how closely they returned to their original lengths on the removal of the pressure. The first eight springs of Table I., A_1 to E, were tested at ordinary atmospheric temperature.

The spring was placed vertically on the faced surface of a specially made bracket, which was itself supported on a stand resting on a stone foundation. A turned steel pin was passed down through the spring, its head resting fair on the upper brass ring, and its lower end having provision for attaching the scale in which the weights were placed. The weight of the pin and scale together was 0·143 kilos. A small, very finely engraved cross was marked on the side of the top ring, and another similarly on the bottom ring of the spring, the points given by these crosses serving as points to which lengths could be measured. The actual measurement was done by means of a very accurate kathetometer, reading with certainty to 0·05 of a millimetre and by estimation to 0·01 of a millimetre. All the readings were taken to two places of decimals, but the last figure is always liable to an error of estimation of about 0·02 of a millimetre. The kathetometer was placed a little over 5 ft. from the spring, and instead of adjusting the level attached to its telescope completely each time a reading was taken, a correction was very carefully determined

once for all for different positions of the bubble in the level, and this correction was added to or subtracted from each reading.

Seven indicators in all were used in the experiments, and ten springs. For brevity's sake we shall refer to these by letters, the use of which will be understood from Table I.

TABLE I.—INDICATORS AND SPRINGS USED IN EXPERIMENTS WITH RICHARDS' INSTRUMENTS.

Reference Letter for: Indicator.	Reference Letter for: Spring.	Maximum Pressure for which Spring was intended.	Diameter of Cylinder.	Ratio of Increase of Stroke by Par. Motion.	Maker.	Remarks.	Reference No. in Original Accounts of Experiments.
			cm.				
A	A_1	6 atmospheres	2·00	3·30	Schäffer & Budenberg	..	221
A	A_2	3 "					
B	B	80 lb. a sq. in.	2·02	3·99	Elliott Brothers	little used	1834
C	C_1	6 kilos a sq. cm.	1·96	3·91	Schäffer & Budenberg	very little used	895
C	C_2	3 "					
D	D_1	10 atmospheres	1·96	3·28	"	..	474
D	D_2	3 "					
E	E	6 "	1·97	3·40	"	a good deal used	306
F	F	60 lb. a sq. in.	2·02	4·07	Elliott Brothers	"	466
G	G	"	2·02	3·99	"	little used	499

The distance between the marks was read first with the spring unloaded, and then with gradually increased loads, placed on the scale until the spring was compressed to an extent corresponding to the maximum pressure for which it was designed. The weights were then removed and a reading made when the spring was once more free. The first and the last readings were compared and the set measured, and then lastly the spring was forcibly extended 3 or 4 mm., and allowed to recover itself, and its length measured again to see whether it had entirely lost any set it might have taken.

The measurements of lengths and pressures were all recorded in millimetres and kilogrammes respectively. The small lengths or alterations of length which are dealt with can be much more easily stated in millimetres than in inches; if inches indeed were used at all, we should have a hundredth of an inch as a unit. All the most important quantities obtained as results of the experiments are ratios and percentages, and therefore quite independent of the units of measurement employed, and applicable directly, without changing one measure into another.

Table II. gives in a condensed form the results of the series of experiments described.

TABLE II.—SPRING A_1.

Original length	46·13 mm.
Final length	46·04 "
Set per cent. of maximum compression	0·59
Length after 3 mm. extension	46·07 mm.
Mean compression a kilogramme	0·89 "

Load Kilos.	Compression Millimetres.	Compression a Kilo.	Difference from Mean. Absolute.	Difference from Mean. Per Cent.	Difference from Final. Absolute.	Difference from Final. Per Cent.
I.	II.	III.	IV.	V.	VI.	VII.
1·5	1·43	0·95	+·06	6·7	+·11	13·1
4·5	3·99	0·89	·00	0·0	+·05	5·9
9·0	7·86	0·87	−·02	2·2	+·03	3·6
13·5	11·62	0·86	−·03	3·3	+·02	2·4
18·0	15·14	0·84	−·05	5·6	·00	0·0

TABLE III.—SPRING A_2.

Original length	45·77 mm.
Final length	45·71 "
Set per cent. of maximum compression	0·33
Length after 5 mm. extension	45·80 mm.
Mean compression a kilogramme	1·79 "

I.	II.	III.	IV.	V.	VI.	VII.
1·14	1·14	1·87	+·08	4·5	+·14	8·1
3·14	5·64	1·79	·00	0·0	+·06	3·5
5·14	9·03	1·76	−·03	1·7	+·03	1·7
7·14	12·33	1·72	−·07	3·9	+·02	1·1
10·50	18·15	1·73	−·06	3·3	·00	0·0